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CUSTOMER REPORT
FOR
MOCK URBAN SETTING TEST

CHRISTOPHER A. BILTOFT

Meteorology & Obscurants Division

WEST DESERT TEST CENTER
U.S. ARMY DUGWAY PROVING GROUND
DUGWAY, UTAH 84022-5000

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The Mock Urban Setting Test (MUST) was conducted for the Defense Threat Reduction Agency (DTRA) at the U.S. Army Dugway Proving Ground (DPG) Horizontal Grid test site on 6-27 September 2001. The experimental objective was to acquire meteorological and dispersion data sets at intermediate scale for use in urban dispersion model development and validation. The MUST design consisted of a regular 12 by 10 array of conex shipping containers (each 12.2 m long, 2.42 m wide, and 2.54 m high) that produced urban-scale roughness over a 200-m square area. A tracer gas (propylene) was released from positions within or immediately outside of the shipping container array and measured using fast-response photoionization detectors (PIDs). MUST included extensive meteorological documentation within and around the test site to characterize flow fields, turbulence, temperature and momentum gradients and fluxes, and atmospheric stability. The 68 MUST trials consisted of 63 continuous releases (16 hours of dispersion measurements) and 5 trials with multiple puff releases (4.75 hours of dispersion measurements). This report provides a detailed description of the MUST experiment and the data available on compact disk (CD).

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The Mock Urban Setting Test (MUST) was conducted at Horizontal Grid, U.S. Army Dugway Proving Ground (DPG) by DPG's West Desert Test Center (WDTC). The MUST experiment, which was sponsored by the Defense Threat Reduction Agency (DTRA), included participants from the Canadian Defence Research Establishment Suffield (DRES), UK Defence Science and Technology Laboratory (DSTL), U.S. Department of Energy (DOE) Los Alamos National Laboratory (LANL), U.S. Army Research Laboratory (ARL), University of Arizona, and University of Utah. WDTC participants included Christopher Biltoft, Roland Barbero, Frederick Baney, Jimmie Calhoun, William Grayson, Mario Sandoval, Pfred Toensing, David Petrie, and George Cochran. Many of these participants put in extra hours beyond their usual duties due to security escort requirements. John Pace (DTRA) and James Bowers (WDTC) provided administrative and technical guidance. Gary Ganong, Edward Toton, and Patrick Cavenee of Logicon RDA made substantial contributions to site documentation and photography. Gary Ganong in particular is credited with providing the detailed conex positions found in Appendix B. Young Yee and Sam Chang from ARL provided additional documentary photography. Mrs. Susan Gross of the WDTC Meteorology & Obscurants Division provided word processing support.

EXECUTIVE SUMMARY

The Mock Urban Setting Test (MUST) was conducted for the Defense Threat Reduction Agency (DTRA) at the U.S. Army Dugway Proving Ground (DPG) Horizontal Grid test site on 6-27 September 2001. The experimental objective was to acquire meteorological and dispersion data sets at intermediate scale for use in urban dispersion model development and validation. MUST collaborators included the U.S. Army Atmospheric Research Laboratory, Canadian Defence Research Establishment Suffield (DRES), UK Defence Science and Technology Laboratory (DSTL), U.S. Department of Energy (DOE) Los Alamos National Laboratory (LANL), and researchers from Arizona State University (ASU) and the University of Utah. This report describes the MUST field program and documents the DPG West Desert Test Center (WDTC) contribution to the MUST database. As MUST collaborator contributions become available, they will be added to this database.

The MUST scaled urban dispersion experiment was designed to overcome the scaling and measurement limitations of laboratory experiments and the characterization difficulties presented by real urban settings. The MUST design consisted of a regular 12 by 10 array of conex shipping containers (each 12.2 m long, 2.42 m wide, and 2.54 m high) that produced urban-scale roughness over a 200-m square area. The container spacing was chosen to establish a wake interference flow regime (see Rotach, 1995) typical of many U.S. and European urban settings.

A tracer gas (propylene) was released from positions within or immediately outside of the shipping container array during the MUST trials. Each release was either a plume from a continuous point source or a series of puffs. Dispersion of the tracer gas through the array was measured using fast-response photoionization detectors (PIDs). PIDs mounted on a 32-m tower and several 6-m towers within the MUST array provided vertical sampling of the dispersing gas, while PIDs distributed along four sampling lines provided lateral dispersion information. The 32-m tower also served as a platform for meteorological profiles and infrared (IR) thermal mapping of the tracer gas. MUST included extensive meteorological documentation within and around the test site to characterize flow fields, turbulence, temperature and momentum gradients and fluxes, and atmospheric stability.

MUST was a collaborative effort by a diverse group of researchers, including both modelers and experimentalists. The opportunities for interaction during MUST and the post-test analyses should provide synergy for a rapid advance in the understanding of urban dispersion processes. Sixty eight useable trial events (63 continuous releases and 5 trials with multiple puff releases) were completed during MUST, resulting in 16 hours of continuous release dispersion data and 4.75 hours of puff data. MUST test data are archived on a set of compact disks (CDs) which will be shared freely among test participants. Preliminary analysis of the PID data indicates that the conex array had a profound influence on dispersion. Details of this influence will emerge as analyses of the MUST data are completed.

SECTION 1. INTRODUCTION

1.1 BACKGROUND

1.1.1 Modern military conflicts and terrorist activities occur with increasing regularity in urban settings. This is a cause for concern because the exposure of large populations to military and terrorist activities presents the possibility of mass casualties when weapons of mass destruction (WMD) are used. Effective mitigation of chemical or biological agent releases in urban settings is predicated upon an understanding of transport and dispersion processes within urban settings. This understanding must be incorporated into the physics of operational urban dispersion models. Such models are needed to develop doctrine; plan counter-proliferation operations; assess, track, and determine the source of hazardous material releases; develop casualty estimates and emergency response plans; and assist in after-the-fact forensic analyses.

1.1.2 Structures within urban settings create their own roughness-induced boundary layers that affect the dispersion of toxic materials in ways that are poorly understood. Although multinational efforts currently are underway to develop urban dispersion models, the data sets available to date to test these models are primarily laboratory (i.e., wind tunnel and water channel) measurements and atmospheric measurements with arrays of small (on the order of 1 m) objects. A few tracer experiments also have been conducted in urban settings. It is not possible to achieve the proper scaling and to take sufficiently detailed roughness layer measurements in laboratory experiments. On the other hand, real cities are overwhelming in their size and complexity, and the release of tracer gases within these settings can be problematic. As a result, there are few adequately scaled and thoroughly documented urban dispersion data sets. The need for a well-documented baseline data set for urban dispersion model development and evaluation has led DTRA to sponsor MUST as an important intermediate step between the laboratory and small-scale atmospheric experiments and a full-scale urban dispersion experiment planned for 2003.

1.1.3 The MUST scaled urban dispersion experiment was designed to overcome the scaling and measurement limitations of laboratory experiments and the characterization difficulties of real urban settings. A 12 by 10 array of shipping (conex) containers was used to produce a wake interference flow regime typical of many U.S. and European cities. [As discussed by Rotach (1995) and others, the wake interference flow regime is intermediate between the isolated flow regime around a single roughness element and the skimming flow regime over densely packed roughness elements.] The approximately 200-m square array created for MUST was sufficiently large to create its own internal urban roughness sublayer, but sufficiently small to be adequately characterized using available instrumentation.

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SECTION 2. TEST SUMMARY

2.1 THE TEST SITE

2.1.1 MUST was conducted at the DPG Horizontal Grid, which is located in the Great Basin desert of western Utah [40° 12.606′ N, 113° 10.635′ W, 1310 m above mean sea level (MSL)]. The test site is predominately flat, with sparse greasewood and sagebrush of 0.5 to 1.0 m height as the predominant vegetation. The surface roughness length z_0 outside the MUST array is within the range of 2 to 4 cm. Terrain features that may influence winds over Horizontal Grid include sand dunes 4 to 6 m in height 1 km to the north, Granite Mountain rising 700 m above the basin floor 12 km to the southwest, and the Cedar Mountains with heights of 600 m above the basin floor 24 km to the northeast. The terrain slope is 0.5 m per kilometer, rising to the south.

2.1.2 Horizontal Grid is comprised of a series of roads formed in a square with a side length of 805 m (0.5 miles). It contains a central 32-m tower and 28 parallel roads spaced at 30-m intervals with an orientation of 240/060°. The gravel and/or crumbling asphalt grid roads are approximately 2 m in width. A power pole with transformers is located 560 m east of the Horizontal Grid tower. Commercial power from these transformers was cabled to the VIP van, which was located at grid center near the base of the 32-m tower, and to two command post (CP) trailers located east of the Horizontal Grid eastern boundary road (refer to Figure 1). The VIP and CP trailers served as data acquisition centers during MUST. Table 1 gives the latitude and longitude of significant positions around Horizontal Grid.

2.1.3 The MUST urban roughness layer was created using conex containers (each 12.2 m long, 2.42 m wide, and 2.54 m high) positioned around the center of Horizontal Grid. As shown in Figure 2, the conex containers were arranged in a 12 by 10 array. Each container was assigned a letter (A through L) and number (0 through 9) to define its position within the array. Container A0 was located in the northeast corner of the array, and containers A0 through A9 defined the northwest border of the conex array. Similarly, containers L0 was located in the southeast corner of the array, and containers L0 through L9 formed the southeast border of the array. As indicated on Figure 2 and in Appendix B, the conex array was not quite square. Small offsets were necessary to avoid guy wires, and several alignment errors occurred due to the disturbance of some survey markers. Appendix B provides details of the conex positions on the MUST grid. The VIP van, identified as VIP in position H5 on Figure 2 and in Appendix B, served as the collection point for WDTC sonic and PID data.

2.1.4 The MUST experiment was designed to accommodate vertical as well as horizontal tracer sampling. The conex array was positioned around a 32-m tower that served as a platform for tracer gas samplers, imagers, and meteorological equipment. Additional temporary 6-m towers were erected in each of the four quadrants (northeast, southeast, northwest, and southwest) as shown on Figure 2 to supplement vertical sampling on the 32-m tower. Short towers also were positioned within the conex array to support detailed wind and turbulence measurements. Climatological analysis indicates that the most frequent winds at Horizontal Grid are from the

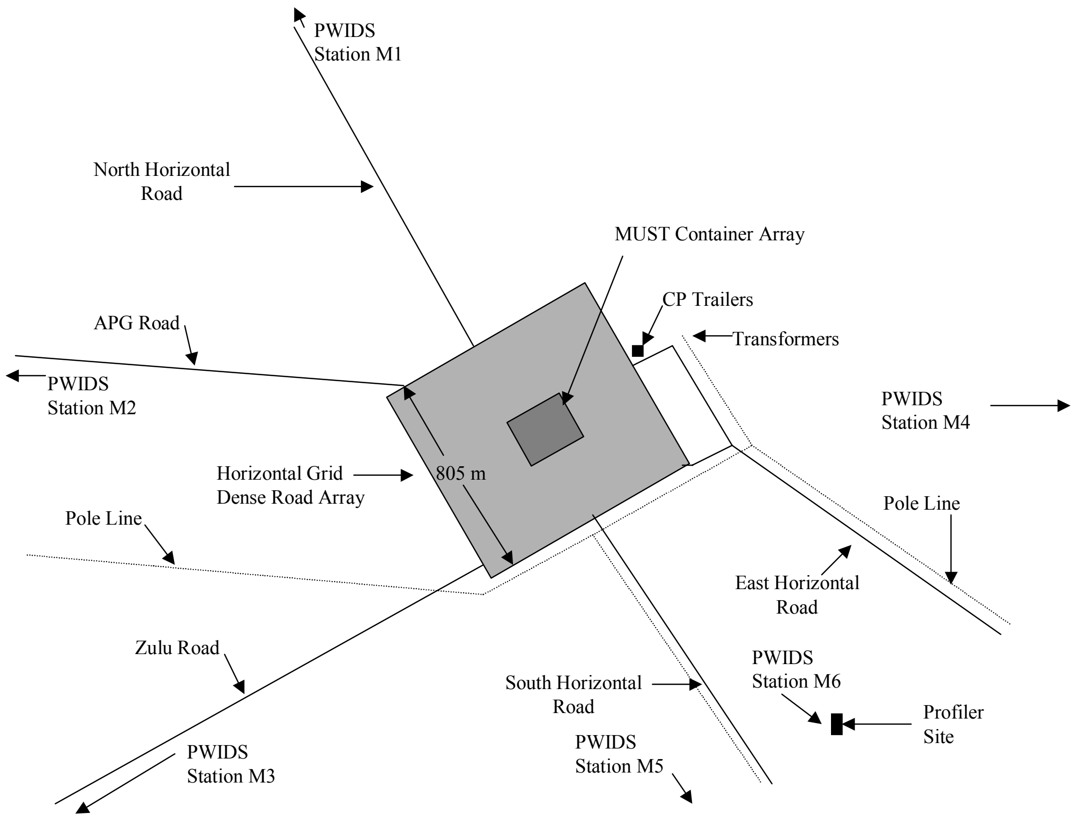

Figure 1. Layout of Horizontal Grid and the surrounding area during the MUST experiment.

southeast and northwest. Consequently, one 16-m pneumatic mast was stationed 30 m northwest of the conex array and another was stationed 30 m to the southeast of the array to document flow immediately upstream and downstream of the conex array.

2.2 TEST DESIGN AND CONDUCT

2.2.1 The MUST experiment was designed to document the effects of an array of large building-like obstacles on flow and dispersion over a range of atmospheric stability regimes (Biltoft, 2001). To that end, tracer gas (propylene) dissemination locations were established upwind of PIDs positioned within the conex array. The dissemination locations are numbered 1 through 37 in Figure 2 (see also Table 3 in Section 2.5). The PIDs were positioned along sampling lines and on towers to obtain information about lateral (crosswind) and vertical plume dimensions during continuous releases, plus information on longitudinal (alongwind) dispersion during puff releases. With PIDs stationed on four sampling lines as shown on Figure 2, dispersion measurements were obtained over distances of several 10s to 100 m or more. Releases were scheduled either from 0200 to 0900 Mountain Daylight Time (MDT) or from 1800 to 2400 MDT to obtain dispersion data over the desired range of wind and stability conditions.

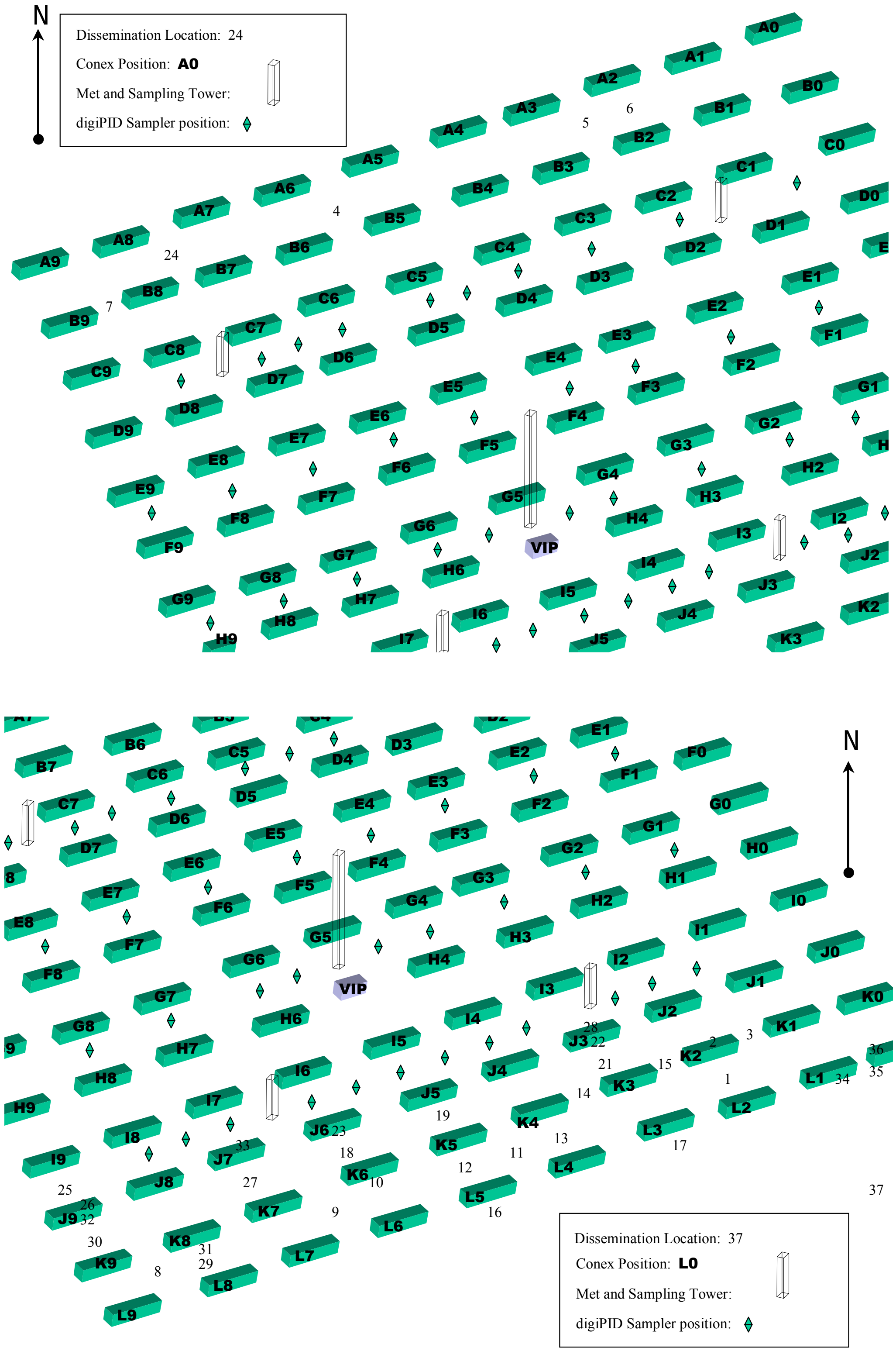

Figure 2. Depiction of the northwest (top) and southeast (bottom) portions of the MUST conex array. Tracer dissemination positions are labeled 1 through 37.

Table 1. MUST Equipment Locations.

Equipment	Latitude (° N)	Longitude (° W)
VIP Van	40.2101	113.1774
NE corner of conex L9	40.2094	113.1777
NE corner of conex L0	40.2101	113.1760
NE corner of conex A9	40.2107	113.1788
NE corner of conex A0	40.2115	113.1770
32-m Tower	40.2102	113.1773
South 16-m pneumatic mast	40.2094	113.1767
North 16-m pneumatic mast	40.2112	113.1782
Tethersonde Site	40.2124	113.1730
Actinometer/FOQT	40.2127	113.1728
ASL Radiometer	40.2123	113.1729
U of U Sodar	40.2122	113.1724
FM-CW Radar	40.1970	113.1676
924-MHz Profiler	40.1981	113.1666
SAMS #8: Horizontal Grid	40.1965	113.1667
SAMS #9: X-Ray Road	40.2426	113.0932
SAMS #15: Salt Flats	40.3409	113.2354
SAMS #16: Cedar Mountain	40.3674	113.0041
PWIDS M1: N. Horizontal	40.2387	113.1935
PWIDS M2: W. Horizontal	40.2119	113.2111
PWIDS M3: Zulu Rd	40.1937	113.1971
PWIDS M4: Radial 36	40.2154	113.1348
PWIDS M5: Burns & Victory	40.1854	113.1513
PWIDS M6: Profiler Site	40.1969	113.1673

2.2.2 Substantial meteorological measurements were made to document conditions during the MUST tracer releases. These measurements included wind and thermodynamic profiles through the boundary layer and detailed flow, turbulence, and temperature and momentum flux measurements upwind, downwind, and within the conex array. Supplemental measurements were made of temperatures on the five exposed surfaces of several conexes, and of temperature profiles within and outside the conex array. Solar and terrestrial radiation also were documented.

2.2.3 MUST experimental data were collected with respect to a common time base. Inter-range instrumentation group (IRIG) time was provided at the VIP van and at one of the two CP trailers. The WDTC and DSTL data acquisition systems were synchronized using the IRIG standard. IRIG time was also made available to other test participants.

2.2.4 WDTC meteorological technicians provided hourly weather observations from the CP area during MUST. These observations, contained on a MUST data CD, included temperature, humidity, winds, pressure, sensible weather, sky condition, and ground condition. The CP trailers also served as the data collection point for the wind and thermodynamic profile and radiative flux measurements.

2.2.5 The MUST array produced a simplified urban setting within a full-scale planetary boundary layer (PBL). The PBL is usually modeled as having an inertial sublayer (ISL) lying above an urban roughness sublayer (RSL) and below the daytime mixed layer (ML) or nocturnal residual layer. Monin-Obukhov similarity (MOS) scaling and the semi-logarithmic wind profile are expected to pertain within the ISL. The ML exhibits height-independent convective velocity or residual layer scaling. The RSL extended to a depth of several canopy (rooftop) heights as a consequence of flow through the MUST array. Because one of the MUST objectives was to acquire sufficient meteorological profiles to assist in developing an appropriate RSL scaling, the MUST design included sufficient measurements to characterize wind profiles, fluxes, and turbulence from within the canopy through the ML.

2.3 TRACER DISSEMINATION AND DETECTION

2.3.1 The tracer dissemination equipment, which was similar to that described by Yee et al. (1993), consisted of three propylene cylinders (Matheson 1F, weighing 82 Newtons (8.4 kg) each) connected through a manifold to a Teledyne Hastings-Raydist mass flow controller. Metered amounts of tracer gas exited the mass flow controller through a 50-m dissemination hose to a polyvinyl chloride (PVC) outlet pipe with a diameter of 0.05 m. The propylene cylinders were immersed in a water bath to minimize changes in cylinder pressure during a release. Tracer gas release rates were controlled to within ±2 percent over user-selected flow rates ranging from 150 to 225 L min^{-1} by mass flow controller electronic circuitry. Puffs of 5-s duration and an estimated 10-L volume were sequentially released using the same equipment. When positioned for a ground or rooftop release, the outlet pipe rested on a wire wheel 0.15 m above the surface, as shown in Figure 3. Otherwise, the pipe stood vertically on its tripod. Tables 2 and 4 in Section 2.5 provide gas release height details. Infrared (IR) imagery contained on MUST data CDs depict near-source plume dispersion.

2.3.2 Factors considered in selecting propylene as the tracer gas included cost, availability, safety and health, and compatibility with the PIDs. Propylene is a commonly used welding gas that is also available in certified quantities admixed with air (nominally 1, 10, 100, 1000 parts per million by volume, ppmv) suitable for use as calibration standards. Propylene is flammable, but is not dangerous or harmful in quantities that could be released through the dissemination system into the open atmosphere. Propylene's photoionization potential of 9.73 electron volts (eV) makes it suitable for use with PIDs containing a lamp rated at 10.6 eV. The advantages of the PID include its relatively low cost and the high (50-Hz) sampling rate, which is needed to develop and test next-generation dispersion models. The use of propylene/PIDs as the tracer/sampler combination is optimal for downwind sampling distances of several tens to several hundreds of meters because gas concentrations within these distances are expected to range from 0.5 to 500 ppmv, well within the PID operating range.

Figure 3. The propylene dissemination pipe (Photo by Chris Biltoft, WDTC).

2.3.3 Biltoft (1995) analyzed the momentum and buoyancy effects of propylene gas exiting a vertically oriented outlet pipe on dissemination equipment of the type used during MUST. The tracer gas exits the outlet pipe at a velocity of less than 1 m s^{-1}, initially rising until its momentum dissipates and then sinking due to negative buoyancy. The momentum-induced plume rise was found to be not more than a few centimeters. Because propylene exceeds the density of air by a factor of 1.4, it can exhibit dense gas effects. Biltoft (1995) found that the propylene cloud usually reaches equilibrium with ambient density within a few tens of centimeters of the top of the outlet pipe. However, the propylene cloud may slump to the ground and pool in calm winds. Biltoft (1995) therefore concluded that momentum and buoyancy have minimal effects on plume height except for nocturnal releases in winds of 1 m s^{-1} or less, when slumping and pooling can occur.

2.3.4 The PIDs used during MUST were the Aurora Scientific, Inc. digital photoionization detector (digiPID) shown in Figure 4 and the Industrial Develop Bangor Ltd. Ultraviolet Ion Collector (UVIC®) shown in Figure 5. These PIDs operate by drawing a stream of air across the face of an ultraviolet lamp that produces ultraviolet (UV) radiation with a photon energy of 10.6 eV. A portion of gas components such as propylene that have an ionization potential less than 10.6 eV is ionized, and these ions are collected on electrically biased plates downstream of the UV lamp. Plate current generated by ion impingement is converted to a signal voltage that is related to concentration through calibration. UVICs feature a direct current (dc)-driven krypton UV lamp that enhances calibration and baseline stability. A flow rate of 40 L min^{-1} through the collector tube minimizes lamp window fouling and ion recombination before collection on the charged plates. The UVICs were calibrated over a range of 0.01 to 1000 ppmv. Data generated at a 50-Hz rate were sent over coaxial cables to a personal computer (PC)-based acquisition and display system. The digiPID features a 20-bit analog-to-digital converter, a 50-Hz frequency response, and a calibrated operating range of 0.04 to 1000 ppmv. All digiPID instrument functions (on-off switching, gain control, zeroing, etc.) were controlled remotely from a PC, which also displayed the data in real time. A total of 48 digiPIDs were either mounted on the 32-m tower for vertical gas concentration profiles or placed on stands at 1.6 m above ground level (AGL) along four sampling lines within the MUST array. Six UVICs were mounted on each of four 6-m towers, one was placed in the wake of a conex container, and another was positioned

Figure 4. Digital photoionization detector (digiPID) mounted on stand with the 32-m tower in the background (Photo by Sam Chang, ARL).

Figure 5. Ultraviolet Ion Collector (UVIC) mounted on a 6-m tower (Photo by Sam Chang, ARL).

next to a digiPID for instrument intercomparison. (Refer to Appendix C for more detailed information on PID locations.) All of the PIDs were oriented towards the southeast, the expected predominant wind direction. A digiPID and UVIC were also calibrated together for quality control. The digiPID and UVIC data will be analyzed and presented as a single data set.

2.4 METEOROLOGICAL MEASUREMENTS AND THERMAL MAPPING

2.4.1 Tethersonde

The AIR, Inc. (currently Vaisala, Inc.) tethersonde is a tethered balloon sounding system consisting of a base station, a helium-filled 9-m^3 balloon, a winch to control balloon height, and battery powered flight equipment suspended below the balloon (see Figure 6). The flight equipment consists of a cup anemometer and vane; temperature, humidity and pressure sensors; and a transponder that transmits flight data to a base station. During MUST, tethersonde flights provided wind and thermodynamic profiles within the ISL and ML between the surface and the desired altitude, nominally 300-1000 m AGL. Wind loading is a limiting factor for tethersonde operations; they were not flown in winds exceeding 8 m s^{-1}. Tethersonde flight profiles, normally performed within 1 hour of each MUST trial, were obtained by the ASU Environmental Fluid Dynamics Group from a position 330 m east of the northeast corner of the must array. Tethersonde data are included on the set of MUST data CDs.

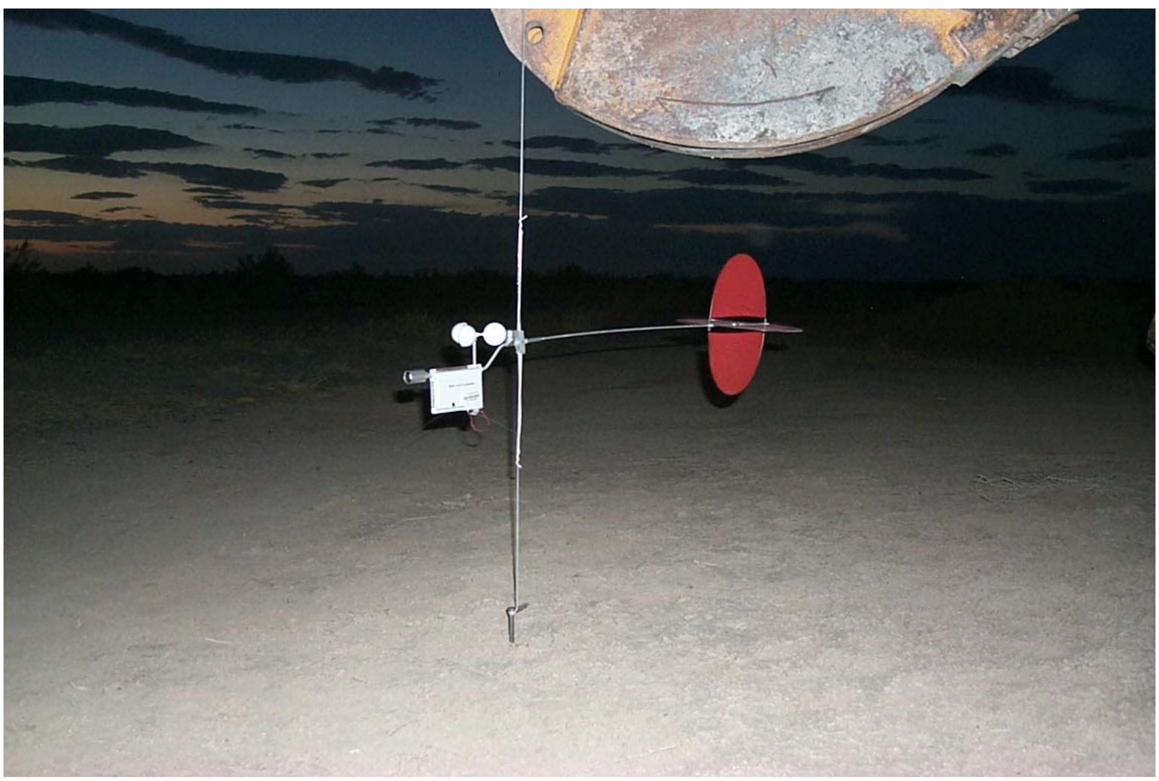

Figure 6. Flight equipment suspended below a tethersonde balloon. (Photo by Young Yee, ARL).

2.4.2 Sonic Anemometer/Thermometer (Sonic)

A sonic anemometer/thermometer (sonic) consists of a transducer array containing paired sets of ultrasonic transducers designed to alternately transmit and receive pulses of acoustic energy, a system clock, and circuitry designed to measure transit time between the transmission and reception of acoustic signals between transducer pairs. Sonics typically have 2- or 3-dimensonal arrays for measuring horizontal wind components or the full wind vector. Sonic output includes wind components and speed of sound at a user-selected rate between 1 and 60 Hz with measurement accuracy of 0.01 to 0.05 m s^{-1}. These data are processed to produce wind and turbulence statistics and fluxes of heat and momentum within the RSL and ISL. WDTC sonics were mounted on the 32-m tower at grid center (4-, 8-, 16-, 24-, 32-m levels), on the 16-m pneumatic masts outside the container array (4-, 8-, 16-m levels), and at 1.15 m AGL between and in front of the conex containers immediately west of the 32-m tower. Additional sonics provided by MUST collaborators were mounted at the 2.4- and 6-m levels on each of the four 6-m towers, near the dissemination source, on the roof of Conex I6, and at several other positions within and outside the array. (Appendix C provides additional information on sonic anemometer positions and data sets.) Figure 7 shows a MUST participant examining the mounting of a DSTL Gill Windmaster sonic anemometer, Figure 8 shows an Applied Technologies, Inc. (ATI) Vx vertical turbulence probe stationed near the VIP van, and Figure 9 shows the ATI Sx probe mounted on the 32-m tower. Images of other types of sonics deployed during MUST are contained on the data summary CD.

Figure 7. Young Yee with DSTL Gill Windmaster Sonic on 6-m tower (Photo by Sam Chang, ARL).

The WDTC sonic anemometer data are contained on one CD. The unedited 10-Hz data are presented in terse ASCII format (no decimal points or spaces), with the start time of the file (MDT) in the file name. Each line of data is associated with a specific 0.1 s time period. Missing data are indicated by –9999 or –999999. Each column of data is specific to one sonic anemometer data channel, and the order of presentation is: (1) the along-axis component (u), (2) the cross-axis component (v), (3) vertical velocity (w) (3-axis sonics only), and (4) speed of sound (c). The u, v, and w channels are five characters in length and speed of sound is seven characters in length. The speed of sound is followed by the cross-axis tilt (t) and along-axis roll (r) of the head for some of the 3-axis sonics mounted on the 32-m tower. (More detailed information on sonic data channels and alignment is presented in Appendix C.) Sonic files begin with two-digit month (MM), day (dd), hour in MDT (hh), minute (mm), and seconds (ss) followed by a location identifier. MMddhhmmssvx.dat indicates 3-axis sonic data from the Vx probes; MMddhhmmssnorth.dat indicates 2-axis sonic data from the north pneumatic mast; MMddhhmmsssouth.dat indicates 2-axis sonic data from the south pneumatic mast; MMddhhmmss_8_METER.dat files contain data from the sonic mounted at 8 m above ground level (AGL) on the 32-m tower; and MMddhhmmssTOWER.dat files contain the 4-, 16-, and 32-m sonic data from the 32-m tower.

Figure 8. ATI Turbulence (Vx) array sonic with the VIP Van and 32-m tower in background. (Photo by Sam Chang, ARL).

Figure 9. ATI 3-axis sonic array (Sx probe) (Photo by Gary Ganong, Logicon RDA).

2.4.3 Fiberoptic-Quartz Thermometer

The Ipitek, Inc. fiberoptic-quartz thermometer (FOQT) is a thermometer connected by optical fiber cabling to four remotely located probes. Each probe houses a quartz crystal machined for a temperature-dependent resonance frequency. The probe's crystal produces a temperature-dependent frequency that is beat against a reference oscillator, producing a temperature-dependent beat frequency that is transmitted to the thermometer for conversion to temperature. Each probe produces a measurement every 2.67 s. The FOQT were used to measure the temperature differences between the surface and 2 m AGL. Use of the quartz crystal and optical fiber eliminates the deleterious effects of stray electromagnetic forces, ground loops, probe heating, and related factors that often make accurate air temperature profiling difficult. The quartz probes were exposed without shielding at the surface of and above an undisturbed patch of ground. Measurement levels were at the surface and 0.01, 0.05, 0.10, 0.25, 0.5, 1.0, and 2.0 m AGL. All probes were assumed to be exposed to comparable radiation loads, eliminating the need for solar exposure correction when used for temperature gradient measurements. Absolute temperature accuracy is strongly influenced by solar radiation absorption, which can elevate the temperature by several degrees Celsius. However, inter-probe accuracy is on the order of ± 0.02 °C. The quartz thermometer system operated continuously during MUST at an undisturbed location approximately 30 m north of the CP trailer. All probes were immersed together in a variable temperature bath prior to and after the test program for quality control. The FOQT experienced periods of data loss due to thermometer box temperature and grounding problems. Available unedited FOQT data are contained on the MUST CD set in the filename.dat format described in Appendix C. These temperature data were recorded with respect to MDT.

2.4.4 Hot-wire Anemometer

A hot-wire anemometer consists of a thin (5- or 12-μm) tungsten wire array consisting of one or more heated wires, each of which is mounted in a Wheatstone bridge connected through a series of amplifiers to a PC-based data recording system. Wire resistance varies with its temperature; air blowing over the heated wire reduces wire temperature. A fast-acting bridge circuit maintains the wire at constant overheat temperature (well above ambient temperature) by sending varying amounts of electrical current through the wire in response to the wind's cooling effect. The result is a measurement of wind flow across the axis of the wire. An array of multiple wires can resolve multiple wind velocity components and features such as velocity gradients and vorticity. Because of the probes' small size and fast response, hot-wire anemometers are used for high frequency (on the order of 1000-Hz) velocity fluctuation measurements. Hot-wire anemometry was used to characterize fine-scale turbulence above the conex container height, but within the RSL. Because of the need for frequent calibration, the hot-wire anemometers sampled only over operator-selected periods during MUST. Integration of hot wires with two miniaturized digiPIDs produced a scalar transport probe (STP), which is described by Metzger and Klewicki (1999). STP measurements of gas concentration and two components of the velocity field at two localized points in the flow provided direct measurement of scalar variance transport. The STP was mounted at 2-m above the roof of Conex I6 near the center of the array in order to sample tracer gas transport within the RSL. Researchers from the University of Utah Department of Mechanical Engineering operated the hot-wire anemometers and STP.

2.4.5 Sound Direction and Ranging (SODAR)

A Doppler acoustic sounder (sodar) is a surface-based remote sensing instrument that uses the acoustic Doppler effect to measure vertical profiles of wind and turbulence. An AeroVironment, Inc. Model 4000 mini-sodar operating at a frequency of 4500 Hz was used during MUST. The Model 4000 antenna consists of a phased array of acoustic transmitters designed to produce a series of acoustic wavefronts that propagate along radial directions oriented towards the vertical and at 16° off the vertical axis towards the east or west and north or south. Energy is backscattered along each radial by turbulent inhomogeneities that the wavefronts encounter as they propagate through the atmosphere. These return signals are Doppler-shifted by the air movement along the radial direction. The Doppler-shifted return signals are time-tagged to determine the height from which they were reflected and are processed into range-resolved velocity components. The radial velocity profiles are subsequently resolved into vertical and horizontal wind component profiles. The Model 4000 sodar, deployed for MUST by the University of Utah Department of Mechanical Engineering, provided 10-min averaged wind profiles between 15 and 200 m AGL in 5-m intervals. It operated continuously throughout MUST from a location 30 m east of the CP trailers. Sodar performance can be characterized in terms of bias, comparability, and precision, all of which vary with sodar settings and meteorological variables. Sodar characterization studies (see, for example, Crescenti, 1999) suggest that sodar measurements are accurate within the range of 0.5 to 1.0 m s^{-1} and 10 to 20 degrees of azimuth during most conditions.

2.4.6 Portable Weather Information and Display System (PWIDS)

The WDTC-developed Portable Weather Information and Display System (PWIDS) station consists of a tripod-mounted propeller-vane wind monitor, a temperature/humidity sensor mounted in a naturally aspirated radiation shield, a data logger, an optically isolated RS-232 interface, and a FreeWave® spread-spectrum radio/modem. Power normally is supplied by a solar panel with battery backup. The measurement height is 2 m AGL. Six PWIDS stations were positioned around Horizontal Grid at distances of several kilometers from grid center to characterize the undisturbed temperature, humidity, and flow fields around the MUST site. Table 1 lists the PWIDS locations. The PWIDS data acquisition rate is 1 Hz, and the data collected during MUST were averaged to 10-s intervals. Accuracies of the Wind Monitor are ± 0.2 m s^{-1} and $\pm$ 3°. The temperature/humidity probes are accurate to ± 0.5 °C and ± 5 percent respectively when aspirated at a flow rate of 2 m s^{-1} or higher. PWIDS data were continuously collected and displayed at the Ditto Weather Station and the CP during MUST. PWIDS data in a filename.dat format are available in the MUST CD collection. These data are presented in Mountain Standard Time (MST).

2.4.7 Surface Atmospheric Measurement System (SAMS)

The Surface Atmospheric Measurement System (SAMS) is a mesometeorological network of data collection platforms (DCPs) connected to a set of PC-compatible workstations. The DCPs are installed at fixed locations across DPG, with the data continuously transmitted by modem to the acquisition control unit for processing, quality control, display, and archival. Each DCP supports an RM Young Wind Monitor at 10 m AGL and Vaisala CS500 temperature, humidity, and pressure probes at 2 m AGL. Some SAMS stations also support solar radiation and precipitation measurement instruments. Sampling is at a rate of 1 Hz except for pressure which is measured once per minute, and the data are archived as 15-min averages. Instantaneous maximum (1-s) wind and maximum and minimum temperature data are also archived for each 15-min period. Accuracies of the Wind Monitor are ± 0.2 m s^{-1} and $\pm$ 3°, and the temperature/ humidity probes are accurate to ± 0.5 °C and ± 5 percent respectively when aspirated at a flow rate of 2 m s^{-1} or higher. Data from SAMS 8 (south of Horizontal Grid), SAMS 9 (east of Horizontal Grid), SAMS 15 (north of Horizontal Grid), and SAMS 16 (Cedar Mountain, northeast of Horizontal Grid) are archived in MST for the MUST test period in a filename.txt format on MUST data CDs. A readme file is available on the CD to describe the file contents.

2.4.8 Thermocouples

Thermocouples consist of contact temperature sensors wired with two dissimilar metals to a reference junction mounted in an isothermal block, and a data acquisition system. Thermocouple operation is based on the Seebeck thermoelectric effect: heating the junction of two dissimilar metal wires induces a flow of current, or a net open circuit voltage. For small temperature changes, the Seebeck voltage is nearly linearly proportional to temperature. Type T (copper-constantan) thermocouples with a self-adhesive backing were attached to the five exposed surfaces of containers G4, G5, G6, and G7 for skin temperature measurements. These thermocouples, which were terminated with 91.4-cm (36- inch) leads, have a response time of 0.3 s or better. The expected temperature measurement accuracy is $\pm$ 1° C. Upon completion of the MUST experiment, these thermocouples were placed together in a common bath. The results are presented in calibration files on a MUST CD. The median bath temperature is recommended as the best estimate of the true thermocouple temperature, and the other thermocouple temperatures should be adjusted accordingly. Thermocouple data were collected with respect to time in MDT at a rate of 1 Hz when the test grid was active, and are available in Excel (filename.xls) format on a MUST data CD. Refer to Appendix C for details of thermocouple locations.

2.4.9 Actinometers

Actinometers produce measurements of solar and terrestrial radiation in Watts per square meter (W m^{-2}). Eppley precision spectral pyranometers and pyrgeometers were used to define the incoming and outgoing long- and short-wave radiation and radiative balance with an accuracy of ± 5 W m^{-2}. Pyranometers measure hemispheric incoming or outgoing short-wave radiation (at wavelengths of 0.3 to 4.0 µm), and pyrgeometers measure hemispheric incoming or outgoing long-wave radiation (the 4.0- to 50-µm band). Pyranometers consist of thermopiles (a series of thermoelectric junctions between two dissimilar metals) covered by a Schott glass dome that is transparent to radiation in the visible part of the spectrum. A temperature gradient is created by placing one set of junctions in thermal contact with a non-wavelength-selective black surface, while isolating the other set. The temperature gradient produces a voltage that is proportional to the temperature difference and hence to the intensity of incident radiation. Pyrgeometers are of similar design except that the covering dome acts as a bandpass filter for long-wave radiation. Two pyranometers and two pyrgeometers were mounted in pairs on a boom 1.5 m above an undisturbed, shadow-free section of ground at an undisturbed site 30 m north of the CP trailer. One of each pair faced towards the sky and the other faced towards the earth's surface. Actinometer readings were logged every 5 s in MDT and were collected continuously during MUST. These unedited data are available in filename.dat format on a data CD.

2.4.10 Infrared Imagers

Infrared (IR) imaging radiometers (imagers) are passive optical devices sensitive to IR radiation in the 8- to 12-µm portion of the spectrum. Because propylene has a broad absorption spectrum between 10 and 12 µm, the passage of propylene across the imager's field of view creates an observable thermal gradient against background temperatures. IR imagers were used to determine initial dimensions and behavior of tracer material released during MUST. The imagers have a typical thermal sensitivity of 0.05 °C, a scan rate of 50 Hz, and 7-bit (128-level) image resolution. Thermal imagers were mounted at the 4- and 30-m levels of the 32-m tower near grid center. Thermal imagery is available for most of the plume releases. The puff releases were difficult to distinguish from background because of the small mass of material released. Imagery of the dissemination is available in IR video and AVI formats.

2.4.11 Wind Profiling Radar

The Radian 924-MHz LAP-3000 radar wind profiler is a ground-based, phased array pulsed radar designed to provide wind profiles in 100-m range gates from 100 m through several kilometers AGL. The radar emits radio energy along radial beams (vertical and tilted towards north or south and east or west) and then listens for returned signals, which are Doppler shifted in frequency by along-radial wind velocity components and reflected back to the radar antenna by density discontinuities in the atmosphere. The time-tagged radial velocity data are then resolved into alongwind, crosswind, and vertical velocity components at each range gate. These velocity components are used to produce vertical profiles of wind speed and direction. The wind profiling radar was stationed 1.5 km south of Horizontal Grid and was operated continuously with 15-min averaging during MUST.

MUST wind profile records from the Horizontal Grid 924-MHz radar wind profiler are available on a data CD. These records are grouped in daily files named WYYJJJ.CNS, where YY is the year (01) and JJJ is the Julian Date. Each record contains header information that includes date, time (in Universal Coordinated Time, UTC), location, and profiler settings and configuration. Wind profiles are presented by height in 60-m range gates. Every record represents a consensus average over a 25-min period. All data were visually examined for any extreme outlier readings.

2.4.12 FM-CW Radar

WDTC's frequency-modulated continuous wave (FM-CW) radar, which was stationed 1.5 km south of the MUST site, uses Bragg scatter from atmospheric refractive index inhomogeneities to observe the turbulence and wave structure within the PBL in fine detail. When pointing vertically and operated in a range-only mode, the FM-CW radar produces time-height refractive index profiles that can be used to identify boundary layer growth and collapse, daytime convection, and wave structure in the nocturnal residual layer. The FM-CW radar uses a linear, continuous, sinusoidal waveform in the 3-GHz range (10-cm wavelength) swept over a 200-MHz band. The frequency emitted at one part of this band propagates vertically, with a portion of the energy backscattered to the receiving antenna where it is differenced against the original transmitted frequency. The resulting beat frequency is proportional to the range at which the backscatter occurred, and the signal magnitude is proportional to the strength of the index of refraction variation. FM-CW radar resolution is on the order of 1 m in range and a few seconds in time, providing detailed boundary layer time-height cross sections.

2.4.13 Microwave Radiometer

Researchers from the ARL Battlefield Environment Directorate brought several sonic anemometers to MUST for in-canopy profile measurements, and a microwave radiometer that was stationed 15 m northeast of the CP trailers. This tripod-mounted radiometer provided potential temperature profile measurements in degrees Kelvin from the surface to 10 km AGL. The radiometer obtains temperature measurements by mapping emission from atmospheric oxygen lines in the 51- to 59-GHz frequency band. Five-minute averaged measurements are provided over range gates with height resolution varying between 100 to 3000 m; higher resolution is found at the lower levels. Microwave radiometer data will be available from ARL on a CD.

2.5 TRACER RELEASE SUMMARY

2.5.1 Tables 2 through 4 summarize the MUST tracer releases. The MUST trials included 285 min of puff releases during 5 trials and 959 min of continuous releases during 63 trials. Puff releases were typically 10 L of propylene per puff disseminated over 5 s. The interval between puff releases was 55 to 115 s, depending on the wind speed. The dissemination rate for the continuous releases ranged from 150 to 225 L/min with release periods between 4 and 23 min. Figure 10 shows an example of propylene concentration measurements made during one of the puff trials (Trial 2681921 on 25 September 2001). The detector number 41 through 48 shown at the left of the figure respectively identify the digiPIDs at the 16-, 12-, 10-, 8-, 6-, 4-, 2-, and 1-m levels of the 32-m tower.

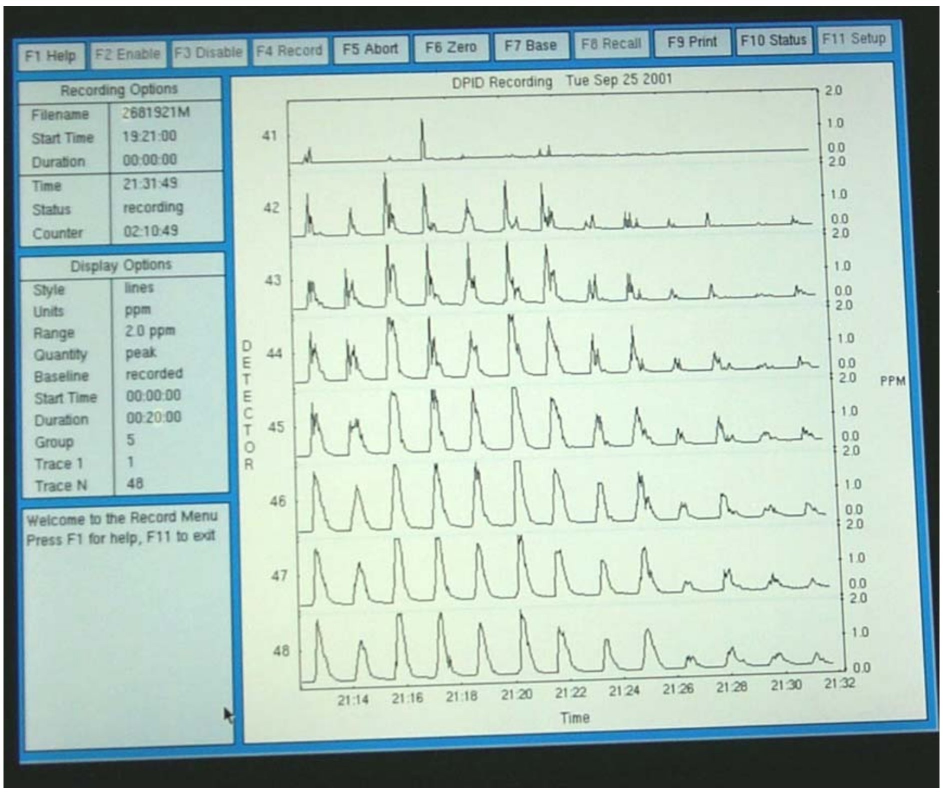

Figure 10. Real-time multi-level display of puff concentrations measured on the 32-m tower during Trial 2681921 on 25 September 2001 (Photo by Young Yee, ARL).

2.5.2 Because of the regularity of conex height and spacing, six different tracer release position types were used during MUST. These position types were assigned letters A through F as follows: (A) 1 m upwind of a conex face; (B) on the road between conex long sides; (C) centered in the intersection between four conexes; (D) on a conex roof; (E) upwind of (outside) the array; and (F) centered in the narrow alley between conex container ends. Table 2 gives the distribution of releases by position and height above ground level (AGL).

Table 2. Distribution of MUST continuous and puff tracer releases by position and height above ground.

Position	Height (m AGL) 0.15	1.3	1.8	2.7	5.2	Total
Upwind Face (A)	9	3	5	--	--	17
Narrow Alley (B)	2	0	2	--	--	4
Intersection (C)	5	0	8	--	--	13
Conex Roof (D)	--	--	--	7	1	8
Outside Array (E)	0	2	2	--	--	4
Wide Alley (F)	10	0	12	--	--	22
Total	26	5	29	7	1	68

2.5.3 The MUST tracer release locations, which are shown on Figure 2, were numbered sequentially with the first release at location 1 on the array and the last at location 37. Multiple releases were frequently made from the same location so that paired comparisons could be made. Table 3 provides a summary of release locations, including position type, position relative to the conex array, and release type (continuous or puff).

2.5.4 Table 4 provides a consolidated summary of the MUST tracer releases between 11 and 27 September 2001 (Julian dates 254 through 270). This summary includes trial name, the time that the gas was turned on, dissemination location, dissemination duration, gas release rate, and whether it was a continuous (C) or puff (P) release. Trial PID data typically include several minutes of baseline measurements before gas release and several minutes of baseline after the gas had cleared the grid. Note that the trials presented in bold type in Table 4 are considered to be of the highest quality (i.e., substantial quantities of the tracer were detected on the central tower and on at least three of the four sampling lines). In addition to the valid trials presented in Table 4, Trials 2610532, 2610622, 2640537, 2650315, and 2650728 were aborted due to a wind shift transporting the tracer off the grid during the release.

Table 3. MUST tracer release locations, positions, and types.

Location	Position Type	Array Position	Number of Trials	
			Continuous	Puff
1	B	K2-L2	2	0
2	D	Roof of K2	2	0
3	F	K1-K2	1	0
4	C	A5-A6-B5-B6	2	0
5	C	A2-A2-B2-B3	3	0
6	B	A2-B2	2	0
7	F	B8-B9	0	1
8	C	K8-K9-L8-L9	2	0
9	C	K6-K7-L6-L7	2	0
10	A	Upwind of K6	4	0
11	C	K4-K5-L4-L5	3	0
12	B	K5-L5	2	0
13	B	K4-L4	1	0
14	F	K3-K4	1	0
15	F	K2-K3	1	0
16	E	4m South of L5	1	0
17	E	4m South of L3	1	0
18	B	J6-K6	3	0
19	B	J5-K5	3	0
21	B	J3-K3	1	0
22	A	Upwind of J3	2	0
23	A	Upwind of J6	2	0
24	C	A7-A8-B7-B8	0	1
25	B	I9-J9	2	0
26	D	Roof of J9	2	0
27	B	J7-K7	1	0
28	D	Roof of J3	1	0
29	B	K8-L8	2	0
30	B	J9-K9	0	1
31	A	Upwind of K8	2	0
32	A	Upwind of J9	1	1
33	D	Roof of J7	1	0
34	A	Upwind of L1	2	0
35	A	Upwind of L0	1	0
36	D	Roof of L0	1	0
37	E	24 m South of L1	1	1

Table 4. Consolidated Summary of MUST Tracer Releases.[a]

Trial Name (JJJhhmm)	Gas on Time (MDT)	Release					
		Location[b]	Position[c]	Height (m AGL)	Duration (min)	Rate (L/min)	Type[d]
2540300	0305	1	F	1.8	15	200	C
2540345	0350	1	F	0.15	15	150	C
2540425	0427	2	D	2.7	15	150	C
2540700	0705	2	D	2.7	15	150	C
2540730	0735	3	F	0.15	15	150	C
2561955	1957	4	C	1.8	17	200	C
2562042	2044	4	C	0.15	15	200	C
2562210	**2212**	**5**	**C**	**1.8**	**16**	**200**	**C**
2562235	**2237**	**5**	**C**	**1.8**	**15**	**225**	**C**
2562257	**2259**	**5**	**C**	**0.15**	**15**	**225**	**C**
2562325	**2328**	**6**	**F**	**1.8**	**15**	**225**	**C**
2562350	2352	6	F	0.15	15	225	C
2570548	0550:30	7	B	1.8	50	225	P
2580637	**0645**	**8**	**C**	**1.8**	**15**	**225**	**C**
2580720	0722	8	C	0.15	4	225	C
2580740	**0741**	**9**	**C**	**1.8**	**15**	**225**	**C**
2580806	**0808**	**9**	**C**	**0.15**	**15**	**225**	**C**
2580831	0833	10	A	0.15	15	225	C
2580855	0857	10	A	1.8	15	225	C
2610220	0222	10	A	1.8	15	200	C
2610458	0500	10	A	1.8	15	200	C
2610543	**0545**	**11**	**C**	**1.8**	**22**	**200**	**C**
2610708	0710:25	12	F	1.8	8:25	200	C
2610731	**0732**	**12**	**F**	**1.8**	**15**	**200**	**C**
2610758	**0759**	**13**	**F**	**0.15**	**15**	**200**	**C**
2620224	**0225**	**1**	**F**	**1.8**	**15**	**200**	**C**
2620246	0246	1	F	0.15	15	200	C
2620307	**0307**	**2**	**D**	**2.7**	**15**	**200**	**C**
2620332	**0332**	**14**	**B**	**0.15**	**16**	**200**	**C**
2620356	**0356**	**15**	**B**	**1.8**	**18**	**200**	**C**
2620433	0433	16	E	1.8	15	225	C
2620502	0502	17	E	1.8	15	225	C
2630415	0417	18	F	1.8	18	175	C
2630446	0447	19	F	1.8	7	175	C
2630636	0637	19	F	1.8	18	175	C
2630701	**0702**	**18**	**F**	**0.15**	**23**	**175**	**C**
2640138	**0145**	**19**	**F**	**0.15**	**21**	**175**	**C**
2640246	**0251**	**21**	**F**	**0.15**	**15**	**200**	**C**
2640314	0314	22	A	0.15	9:30	200	C
2640425	0428:10	23	A	0.15	9:57	200	C

Table 4. Consolidated Summary of MUST Tracer Releases (Cont'd).[a]

Trial Name (JJJhhmm)	Gas on Time (MDT)	Release					
		Location[b]	Position[c]	Height (m AGL)	Duration (min)	Rate (L/min)	Type[d]
2640638	0639	23	A	0.15	8	200	C
2640701	**0702**	**22**	**A**	**0.15**	**16**	**200**	**C**
2650548	0548	24	C	1.8	44	175	P
2671852	**1852**	**25**	**F**	**0.15**	**22**	**200**	**C**
2671934	**1935**	**25**	**F**	**1.8**	**15**	**200**	**C**
2672003	**2004**	**26**	**D**	**2.7**	**15**	**200**	**C**
2672033	**2034**	**27**	**F**	**1.8**	**15**	**200**	**C**
2672101	2102	18	F	0.15	14	200	C
2672150	**2151**	**22**	**A**	**0.15**	**16**	**200**	**C**
2672213	**2213**	**22**	**A**	**1.8**	**15**	**200**	**C**
2672235	**2235**	**28**	**D**	**2.7**	**15**	**200**	**C**
2672303	**2304**	**11**	**C**	**1.8**	**19**	**200**	**C**
2672338	2339	11	C	0.15	14	200	C
2681829	**1830**	**29**	**F**	**1.8**	**15**	**225**	**C**
2681849	**1849**	**29**	**F**	**0.15**	**16**	**225**	**C**
2681921	**1923**	**30**	**F**	**1.8**	**133**	**225**	**P**
2682150	**2151**	**31**	**A**	**1.8**	**15**	**225**	**C**
2682211	2211	31	A	0.15	15	225	C
2682234	**2234**	**32**	**A**	**0.15**	**18**	**225**	**P**
2682256	**2256**	**32**	**A**	**0.15**	**15**	**225**	**C**
2682320	**2321**	**26**	**D**	**2.7**	**15**	**225**	**C**
2682353	**2354**	**33**	**D**	**5.2**	**15**	**225**	**C**
2692054	2055	34	A	1.3	22	225	C
2692131	**2132**	**35**	**A**	**1.3**	**17**	**225**	**C**
2692157	**2158**	**36**	**D**	**2.7**	**15**	**225**	**C**
2692223	**2224**	**34**	**A**	**1.3**	**15**	**225**	**C**
2692250	**2251**	**37**	**E**	**1.3**	**17**	**225**	**C**
2692314	2314	37	E	1.3	40	225	P

[a] Trials presented in bold type are considered to be of the highest quality (i.e., substantial quantities of the tracer were detected on the central tower and on at least three of the four sampling lines).
[b] See Figure 2.
[c] Position Type A = 1 m upwind of a conex container face, B = centered between container ends, C = centered in the intersection between four containers, D = on a container roof, E = upwind of the array, and F = on the road between container long sides.
[d] Release type C = continuous and P = puff.

2.6 CONCLUSIONS AND RECOMMENDATIONS

The MUST was a highly successful field experiment designed to bridge the gap between laboratory and full scale urban flows. Sufficient instrumentation was available to characterize the state of the undisturbed boundary layer, and the effects of the conex array on flow and dispersion within the surface boundary layer. Meteorological and dispersion data were collected over a wide variety of wind and stability conditions. These data should be very useful for the development and validation of urban dispersion models.

MUST data sets are available on CDs. One WDTC-generated CD contains .jpg images, SAMS, PWIDS, FOQT, conex temperature, actinometer, and wind profiler data. A second CD contains trial-related WDTC sonic anemometer data. Other test participants are producing data sets and analyses on separate CDs. These data sets will be shared freely among MUST collaborators. Other potential users should contact DTRA or test program participants for access to MUST data sets.

Analyses of MUST data sets are incomplete as of the date of this report, so it is not possible to draw definitive conclusions at this time. However, it became evident during the conduct of the experiments that the conex array had a substantial impact on dispersion. Because conex containers are easily positioned and stacked, they are very useful for designing near-full scale urban dispersion experiments. MUST was conducted using the simplest possible conex array configuration. Follow-on experiments should include more complex configurations that more closely resemble real urban environments.

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APPENDIX A. REFERENCES

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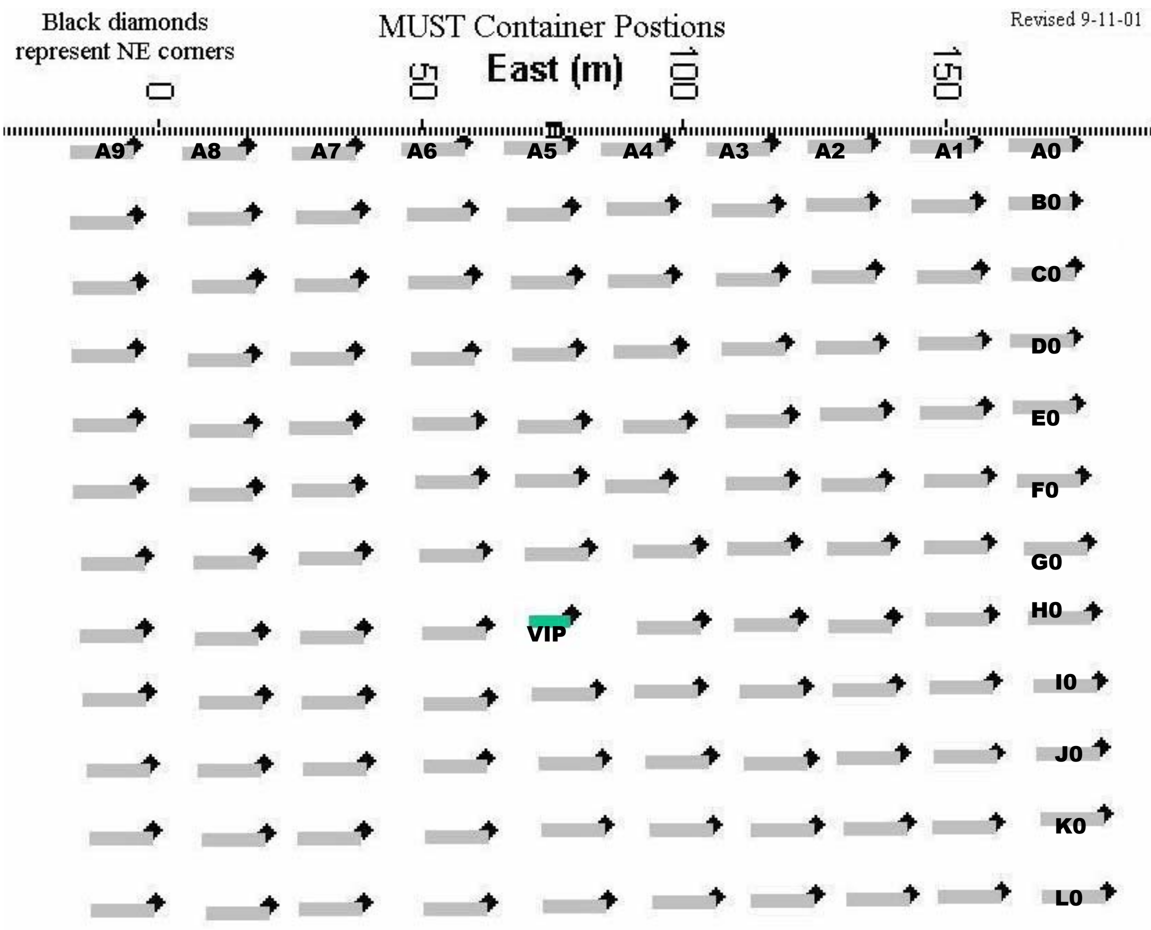
APPENDIX B. CONEX POSITIONS

B.1 Conex Positions in the MUST Array



B.2 MUST Conex Container NE Corner Locations

The North row of the MUST container array is the A row.
The South row of the MUST container array is the L row.
The East column of the MUST container array is the 0 column.
The West column of the MUST container array is the 9 column.
The origin of the coordinate system is the intersection of two lines NW of the NW corner of container A8.
The X axis points South.
The Y axis points East.
The NE corner of container A9 is A91.
The NW corner of container A8 is A84.

Lines 17 to 45 list the calculations of the Y coordinates.
Lines 48 to 82 list the calculations of the X coordinates.
Lines 86 to 206 list the x and y coordinates of the NE corners of the containers.

	AY (m)	BY (m)	CY (m)	DY (m)	EY (m)	FY (m)	GY (m)	HY (m)	IY (m)	JY (m)	KY (m)	LY (m)
A91	-5	-4.67	-3.98	-4.62	-4.6	-4.14	-2.97	-3.12	-2.45	-1.66	-1.42	-0.92
A8-A9	9.78	10.24	10.02	10.31	10.12	10.15	9.64	10.39	10.12	9.58	9.59	9.65
A84	4.78	5.57	6.04	5.69	5.52	6.01	6.67	7.27	7.67	7.92	8.17	8.73
a81	16.96	17.75	18.22	17.87	17.7	18.19	18.85	19.45	19.85	20.1	20.35	20.91
A7-A8	8.34	8.63	7.67	7.49	7.68	7.45	7.72	7.4	7.41	7.04	6.53	6.05
A74	25.3	26.38	25.89	25.36	25.38	25.64	26.57	26.85	27.26	27.14	26.88	26.96
A71	37.48	38.56	38.07	37.54	37.56	37.82	38.75	39.03	39.44	39.32	39.06	39.14
A6-A7	8.39	8.28	9.22	10.15	10.93	11.3	11.07	10.92	11.06	10.85	11.34	11.31
A64	45.87	46.84	47.29	47.69	48.49	49.12	49.82	49.95	50.5	50.17	50.4	50.45
A61	58.05	59.02	59.47	59.87	60.67	61.3	62	62.13	62.68	62.35	62.58	62.63
A5-A6	7.76	7.56	7.34	7.75	7.8	6.86	7.8	10.84	8.87	9.85	10.29	10.56
A54	65.81	66.58	66.81	67.62	68.47	68.16	69.8	72.97	71.55	72.2	72.87	73.19
A51	77.99	78.76	78.99	79.8	80.65	80.34	81.98	78.7	83.73	84.38	85.05	85.37
A4-A5	6.74	6.6	6.82	7.26	7.95	4.99	8.87	12.64	7.41	8.55	8.61	8.58
A44	84.73	85.36	85.81	87.06	88.6	85.33	90.85	91.34	91.14	92.93	93.66	93.95
A41	96.91	97.54	97.99	99.24	100.78	97.51	103.03	103.52	103.32	105.11	105.84	106.13
A3-A4	7.7	7.95	8.28	8.03	7.5	10.68	6.02	6.47	7.7	6.97	7.2	7.11
A34	104.61	105.49	106.27	107.27	108.28	108.19	109.05	109.99	111.02	112.08	113.04	113.24
A31	116.79	117.67	118.45	119.45	120.46	120.37	121.23	122.17	123.2	124.26	125.22	125.42
A2-A1	7.01	6.3	5.91	5.8	6.15	6.08	6.12	5.92	5.29	5.38	5.35	5.59
A24	123.8	123.97	124.36	125.25	126.61	126.45	127.35	128.09	128.49	129.64	130.57	131.01
A21	135.98	136.15	136.54	137.43	138.79	138.63	139.53	140.27	140.67	141.82	142.75	143.19
A1-A2	7.36	7.78	8.1	7.44	6.88	7.09	6.38	6.38	6.56	5.83	5.03	5.58
A14	143.34	143.93	144.64	144.87	145.67	145.72	145.91	146.65	147.23	147.65	147.78	148.77
A11	155.52	156.11	156.82	157.05	157.85	157.9	158.09	158.83	159.41	159.83	159.96	160.95
A0-A1	6.98	6.53	5.62	5.57	5.05	6.11	6.91	7.27	7.6	7.62	8.07	7.77
A04	162.5	162.64	162.44	162.62	162.9	164.01	165	166.1	167.01	167.45	168.03	168.72
A01	174.68	174.82	174.62	174.8	175.08	176.19	177.18	178.28	179.19	179.63	180.21	180.9

Lines 48 to 82 list the X coordinates.

	X9 (m)	X8 (m)	X7 (m)	X6 (m)	X5 (m)	X4 (m)	X3 (m)	X2 (m)	X1 (m)	X0 (m)

A91	3.06	2.93	2.84	2.56	2.62	2.3	2.35	2.39	2.23	2.41
A92	5.48	5.35	5.26	4.98	5.04	4.72	4.77	4.81	4.65	4.83
B91-A92	12.97	12.57	12.25	12.29	11.5	11.61	11.09	10.87	10.8	10.56
B91	18.45	17.92	17.51	17.27	16.54	16.33	15.86	15.68	15.45	15.39
B92	20.87	20.34	19.93	19.69	18.96	18.75	18.28	18.1	17.87	17.81
C91-B92	12.3	12.62	12.57	12.6	13.22	13.13	13.18	13.04	12.86	12.41
C91	33.17	32.96	32.5	32.29	32.18	31.88	31.46	31.14	30.73	30.22
C92	35.59	35.38	34.92	34.71	34.6	34.3	33.88	33.56	33.15	32.64
D91-C92	12.86	13.97	13.92	14.09	13.51	13.42	13.28	13.18	13.06	13.29
D91	48.45	49.35	48.84	48.8	48.11	47.72	47.16	46.74	46.21	45.93
D92	50.87	51.77	51.26	51.22	50.53	50.14	49.58	49.16	48.63	48.35
E91-D92	12.98	13.14	13.13	13.02	13.64	13.86	13.63	12.58	12.59	12.04
E91	63.85	64.91	64.39	64.24	64.17	64	63.21	61.74	61.22	60.39
E92	66.27	67.33	66.81	66.66	66.59	66.42	65.63	64.16	63.64	62.81
F91-E92	12	11.88	11.28	9.99	10.08	10.68	11.69	12.75	13.18	13.48
F91	78.27	79.21	78.09	76.65	76.67	77.1	77.32	76.91	76.82	76.29
F92	80.69	81.63	80.51	79.07	79.09	79.52	79.74	79.33	79.24	78.71
G91-F92	13.46	12.4	12.8	13.88	13.23	12.21	11.88	12.12	12.16	12.58
G91	94.15	94.03	93.31	92.95	92.32	91.73	91.62	91.45	91.4	91.29
G92	96.57	96.45	95.73	95.37	94.74	94.15	94.04	93.87	93.82	93.71
H91-G92	14.08	14.75	14.92	14.35	12.63	14.39	14.09	14.27	13.74	13.04
H91	110.65	111.2	110.65	109.72	107.37	108.54	108.13	108.14	107.56	106.75
H92	113.07	113.62	113.07	112.14	109.79	110.96	110.55	110.56	109.98	109.17
I91-H91	11.65	11.7	12.2	13.63	14.51	12.75	12.61	12.29	12.34	12.83
I91	124.72	125.32	125.27	125.77	124.3	123.71	123.16	122.85	122.32	122
I92	127.14	127.74	127.69	128.19	126.72	126.13	125.58	125.27	124.74	124.42
J91-I92	13.39	13.17	12.58	11.61	12.72	12.96	13.66	13.29	13.55	12.87
J91	140.53	140.91	140.27	139.8	139.44	139.09	139.24	138.56	138.29	137.29
J92	142.95	143.33	142.69	142.22	141.86	141.51	141.66	140.98	140.71	139.71
K91-J92	12.88	13.01	13.05	13.2	12.56	12.81	12.65	12.92	12.7	12.42
K91	155.83	156.34	155.74	155.42	154.42	154.32	154.31	153.9	153.41	152.13
K92	158.25	158.76	158.16	157.84	156.84	156.74	156.73	156.32	155.83	154.55
L91-K92	13.19	13.4	13.64	13.83	14.29	13.5	13.32	13.27	13.57	14.52
L91	171.44	172.16	171.8	171.67	171.13	170.24	170.05	169.59	169.4	169.07

Lines 86 to 206 list the X and Y coordinates of the NE corners of the containers.

	X (m)	Y (m)
A91	3.06	-5
A81	2.93	16.96
A71	2.84	37.48
A61	2.56	58.05
A51	2.62	77.99
A41	2.3	96.91
A31	2.35	116.79
A21	2.39	135.98
A11	2.23	155.52
A01	2.41	174.68
B91	18.45	-4.67
B81	17.92	17.75

B71	17.51	38.56
B61	17.27	59.02
B51	16.54	78.76
B41	16.33	97.54
B31	15.86	117.67
B21	15.68	136.15
B11	15.45	156.11
B01	15.39	174.82
C91	33.17	-3.98
C81	32.96	18.22
C71	32.5	38.07
C61	32.29	59.47
C51	32.18	78.99
C41	31.88	97.99
C31	31.46	118.45
C21	31.14	136.54
C11	30.73	156.82
C01	30.22	174.62
D91	48.45	-4.62
D81	49.35	17.87
D71	48.84	37.54
D61	48.8	59.87
D51	48.11	79.8
D41	47.72	99.24
D31	47.16	119.45
D21	46.74	137.43
D11	46.21	157.05
D01	45.93	174.8
E91	63.85	-4.6
E81	64.91	17.7
E71	64.39	37.56
E61	64.24	60.67
E51	64.17	80.65
E41	64	100.78
E31	63.21	120.46
E21	61.74	138.79
E11	61.22	157.85
E01	60.39	175.08
F91	78.27	-4.14
F81	79.21	18.19
F71	78.09	37.82
F61	76.65	61.3
F51	76.67	80.34
F41	77.1	97.51
F31	77.32	120.37
F21	76.91	138.63
F11	76.82	157.9
F01	76.29	176.19
G91	94.15	-2.97
G81	94.03	18.85

G71	93.31	38.75
G61	92.95	62
G51	92.32	81.98
G41	91.73	103.03
G31	91.62	121.23
G21	91.45	139.53
G11	91.4	158.09
G01	91.29	177.18
H91	110.65	-3.12
H81	111.2	19.45
H71	110.65	39.03
H61	109.72	62.13
H51	107.37	78.7
H41	108.54	103.52
H31	108.13	122.17
H21	108.14	140.27
H11	107.56	158.83
H01	106.75	178.28
I91	124.72	-2.45
I81	125.32	19.85
I71	125.27	39.44
I61	125.77	62.68
I51	124.3	83.73
I41	123.71	103.32
I31	123.16	123.2
I21	122.85	140.67
I11	122.32	159.41
I01	122	179.19
J91	140.53	-1.66
J81	140.91	20.1
J71	140.27	39.32
J61	139.8	62.35
J51	139.44	84.38
J41	139.09	105.11
J31	139.24	124.26
J21	138.56	141.82
J11	138.29	159.83
J01	137.29	179.63
K91	155.83	-1.42
K81	156.34	20.35
K71	155.74	39.06
K61	155.42	62.58
K51	154.42	85.05
K41	154.32	105.84
K31	154.31	125.22
K21	153.9	142.75
K11	153.41	159.96
K01	152.13	180.21
L91	171.44	-0.92
L81	172.16	20.91

L71	171.8	39.14
L61	171.67	62.63
L51	171.13	85.37
L41	170.24	106.13
L31	170.05	125.42
L21	169.59	143.19
L11	169.4	160.95
L01	169.07	180.9

B.3 Conex Yaw Angles

The MUST containers were placed in a rectangular array as shown in Figure B2 (not to scale). Due to the presence of a guyed tower in the center of the array and the other features of the testbed, the rectangular array had displacement, yaw and tilt errors (deviations from the idealized configuration). To describe these errors, two reference lines were established: one pointing to 62.75° and one pointing to 152.86°. The containers were placed in 10 North-South columns (9 to 0) and 12 East-West rows (A to L). The conex array alignment is 27.14° counter clockwise from true north, or along the 152.86° reference line shown in Figure B.2. Grid "north" is normal to the rows, ignoring the difference between the grid alignment and true north. The grid axes are defined with x increasing toward the "south" and y increasing towards the "east" so that the origin is near the "northwest" corner of the domain and most of the points on the grid have positive x and y values. The twelve rows of containers are aligned from "west" to "east", with the containers' long axes approximately parallel to the 62.75° reference line. The "northern"-most row is Row A and the "southern"-most row is Row L. The ten columns of containers are aligned from "north" to "south" with the "western"-most column defined as Column 9 and the "eastern"-most column as Column 0. Some of the peripheral containers are labeled in Figure B2.

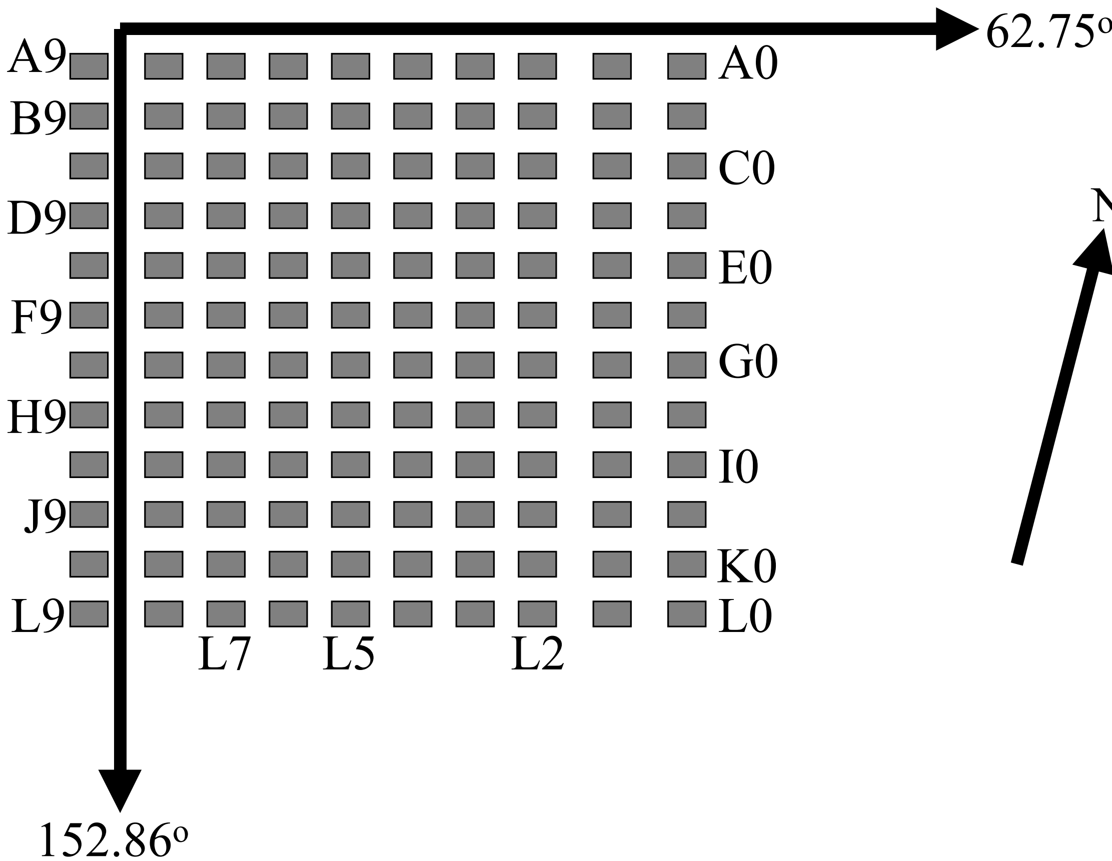


Figure B2. The MUST container layout, showing the two reference lines pointing to 62.75° and 152.86° (not to scale).

Figure B3 shows the relationship of the Northeast container (A0) to the 62.75° reference line. The yaw angle can be defined as:

Arcsine (yaw angle of A0) = (A01x –A04x) / (Length of A0)

For small angles, the angle and the sine of the angle are approximately equal.

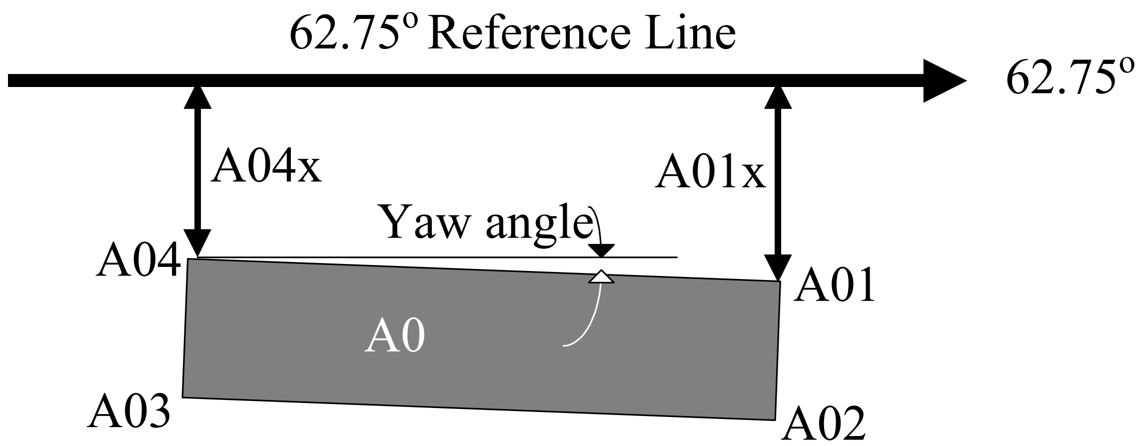


Figure B3. The relationship of the Northeast container (A0) to the 62.75° reference line and the numbering of the four corners of the container A0.

Figure B4 shows the geometry for the container in the second row (B0).

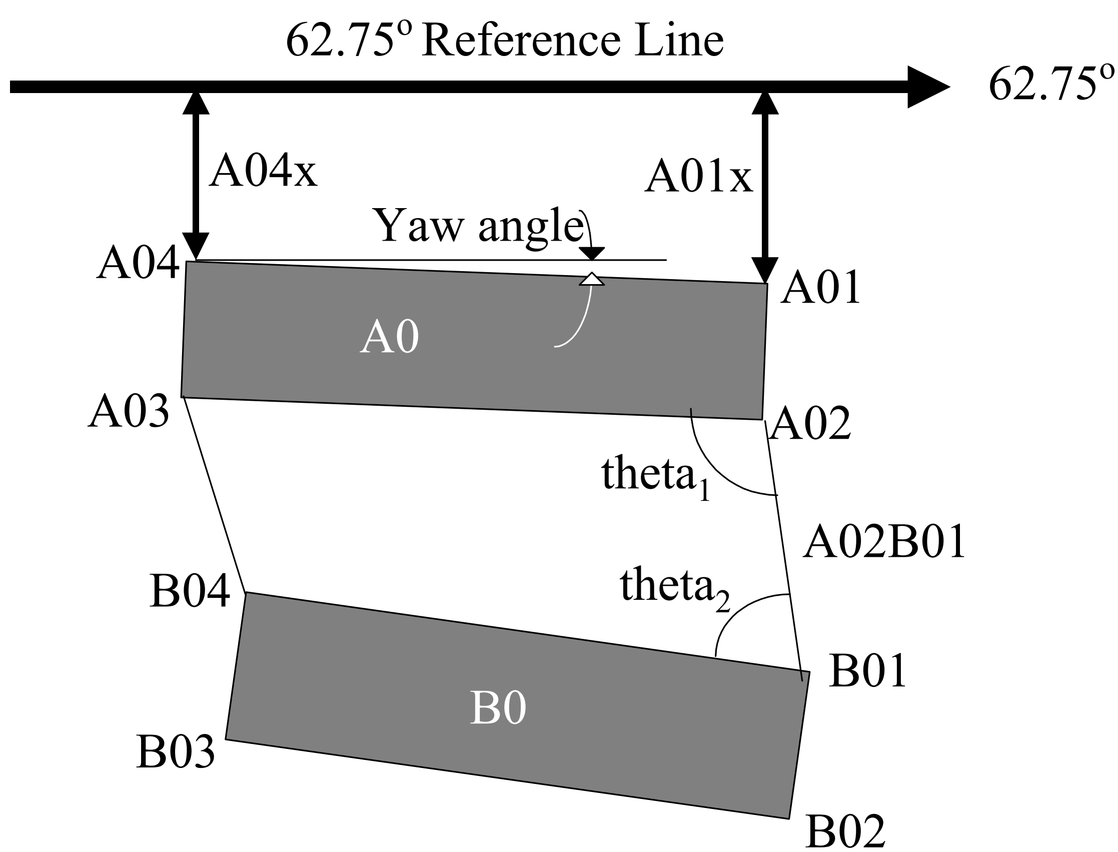


Figure B4. The relationship of the first two containers in Column 0 and the angles of rotation.
(Yaw angle of B0) = (Yaw angle of A0) + 180 – $theta_1$ – $theta_2$

Using the law of cosines,

L_1 = length of container A0
AB = distance from A02 to B01
d_1 = distance from A03 to B01

$$\text{cosine}(\text{theta}_1) = (L_1^2+(AB)^2-d_1^2)/(2L_1 (AB))$$

L_2 = length of container B0
AB = distance from A02 to B01
d_2= distance from A02 to B04

$$\text{cosine}(\text{theta}_2) = (L_2^2+(AB)^2-d_2^2)/(2L_2 (AB))$$

In general, one can proceed down Column 0,

$$(\text{Yaw angle of n0}) = (\text{Yaw angle of (n-1)0}) + 180 - \text{theta}_{n1} - \text{theta}_{n2}$$

and for the m^{th} column,

$$(\text{Yaw angle of nm}) = (\text{Yaw angle of (n-1)m}) + 180 - \text{theta}_{nm1} - \text{theta}_{nm2}$$

The resulting yaw angles are listed in Table B1, where positive angles are clockwise yaws. The largest yaw angle was 4 degrees, for H5, an instrumentation van used instead of a container at that location. The largest container yaw angle was 3.1 degrees.

Table B1. MUST container yaw angles (positive is clockwise).

	Yaw Angle (degrees)									
	Row									
Column	0	1	2	3	4	5	6	7	8	9
A	1.8	0.3	-0.1	-0.2	-0.2	-1.0	-2.3	0.1	-0.1	0.7
B	2.4	-0.7	-0.7	-0.8	-1.4	-1.8	-1.5	-1.7	-2.4	-1.8
C	-1.2	-0.5	-0.5	-0.5	0.3	0.5	-0.6	0.7	-0.1	-0.1
D	-1.2	-1.5	-1.3	-1.4	-0.8	-0.6	0.8	1.0	0.4	0.1
E	-2.1	-0.6	-2.7	-1.1	-1.5	0.0	-0.1	0.3	-0.2	0.0
F	-0.7	-1.0	-0.2	0.7	2.5	3.0	-0.8	-1.0	-1.2	2.1
G	-0.5	1.1	-0.3	-0.7	0.5	-1.8	0.3	-0.8	-1.0	-1.6
H	-0.6	-0.6	0.4	0.2	-0.9	-4.0	0.4	-1.5	-0.1	1.4
I	1.1	1.2	-0.6	-1.5	0.3	0.0	3.1	0.1	0.4	1.0
J	-1.4	0.6	-0.5	-0.5	0.5	0.6	0.6	-0.9	0.9	-0.9
K	-0.3	-0.2	-0.9	-0.3	1.3	-1.5	-0.3	-0.5	-1.2	-1.4
L	-0.1	-0.3	-0.8	0.7	-0.1	0.7	0.6	-1.6	0.3	1.3

(G. Ganong, 14 Nov 01)

B.4 Conex Tilt Angles

MUST Container Tilt

Measurements made on NE corners of containers.
The corners are the most rigid vertical members.
90 degrees is vertical
Less than 90 degrees leans towards the North.
More than 90 degrees leans towards the South.

Row	A	B	C	D	E	F	G	H	I	J	K	L
0.0	91.1	89.1	90.0	90.7	90.3	88.6	89.1	88.8	89.7	88.5	89.3	88.5
1.0	88.8	91.4	90.0	90.7	90.7	89.9	88.2	89.5	89.9	90.8	88.9	89.6
2.0	90.0	89.9	89.5	91.1	89.4	90.7	89.7	89.4	89.5	89.5	91.4	89.7
3.0	90.0	89.3	89.7	90.1	90.6	91.6	88.8	88.2	89.4	89.8	88.7	90.0
4.0	90.3	90.0	89.5	92.2	91.4	91.3	90.4	91.3	89.6	89.4	89.9	90.0
5.0	90.6	89.0	91.1	90.5	88.9	89.6	90.9	90.4	88.5	89.7	90.1	90.5
6.0	87.3	90.2	90.6	90.2	90.5	89.1	89.1	89.9	91.4	89.5	89.5	89.6
7.0	88.4	89.6	89.9	91.0	90.4	89.7	89.1	90.0	90.1	89.0	88.7	89.5
8.0	90.0	89.7	90.7	91.9	88.7	91.5	88.3	88.6	89.3	88.8	90.6	89.9
9.0	91.3	90.6	90.0	90.1	88.2	90.0	91.0	90.0	91.0	88.4	88.6	89.5
Sum	897.8	898.8	901.0	908.5	899.1	902.0	894.6	896.1	898.4	893.4	895.7	896.8
Min	87.3	89.1	89.5	90.1	88.2	88.6	88.2	88.2	88.5	88.4	88.6	88.5
Max	91.3	91.4	91.1	91.9	91.4	91.6	90.9	91.3	91.4	90.8	91.4	90.5

Overall Minimum	87.3	Min Tilt Angle	-2.7
Overall Maximum	91.6	Max Tilt Angle	1.6

APPENDIX C EQUIPMENT POSITIONS

C.1 Locations of digiPIDs

a. First Sampling Line (Sampling Height 1.6 m AGL)

Detector 1: centered between J1, J2, I1, I2
Detector 2: centered between J2 and I2
Detector 3: centered between J2, J3, I2, I3
Detector 4: centered between J3, J4, I3, I4
Detector 5: centered between J4 and I4
Detector 6: centered between J4, J5, I4, I5
Detector 7: centered between J5 and I5
Detector 8: centered between J5, J6, I5, and I6
Detector 9: centered between J6 and I6
Detector 10: centered between J7 and I7
Detector 11: centered between J7, J8, I7, and I8
Detector 12: centered between J8 and I8

b. Second Sampling Line (Sampling Height 1.6 m AGL)

Detector 13: centered between H1 and G1
Detector 14: centered between H2 and G2
Detector 15: centered between H3 and G3
Detector 16: centered between H4 and G4
Detector 17: centered between H4, H5, G4, and G5
Detector 18: centered between H5, H6, G5, and G6
Detector 19: centered between H6 and G6
Detector 20: centered between H7 and G7
Detector 21: centered between H8 and G8

c. Third Sampling Line (Sampling Height 1.6 m AGL)

Detector 22: centered between F1 and E1
Detector 23: centered between F2 and E2
Detector 24: centered between F3 and E3
Detector 25: centered between F4 and E4
Detector 26: centered between F5 and E5
Detector 27: centered between F6 and E6
Detector 28: centered between F7 and E7
Detector 29: centered between F8 and E8
Detector 30: centered between F9 and E9

d. Fourth Sampling Line (Sampling Height 1.6 m AGL)

Detector 31: centered between D0, D1, C0 and C1

Detector 31: centered between D2 and C2
Detector 33: centered between D3 and C3
Detector 34: centered between D4 and C4
Detector 35: centered between D4, D5, C4, and C5
Detector 36: centered between D5 and C5
Detector 37: centered between D6 and C6
Detector 38: centered between D6, D7, C6, and C7
Detector 39: centered between D7 and C7
Detector 40: centered between D8 and C8

e. 32-m Tower

Detector 41: 16 m AGL
Detector 42: 12 m AGL
Detector 43: 10 m AGL
Detector 44: 8 m AGL
Detector 45: 6 m AGL
Detector 46: 4 m AGL
Detector 47: 2 m AGL
Detector 48: 1 m AGL

C.2 Locations of UVICs within the Conex Array. Data from UVICs on the northwest and southwest quadrant towers were collected on computer A, and data from the UVICs on the northeast and southeast quadrant towers were collected on computer B. The location of each UVIC and its associated data channel number are given in Table C-1. Binary (.bin) UVIC data and associated header (.hdr) files have filenames defined by the Julian date (JJJ), hour in MDT (hh), and minute (mm) of the trial start time, followed by an A or B for the computer on which the data originated. Refer to the MUST Trial Notes for UVICs and Sonics (Beck et al., 2001) for further details.

Table C-1. Six-Meter Tower UVIC Locations (11 through 43) and Channel Numbers (A1 through B15) by Height and Trial Name.

Height	Quadrant	2562042- 2562257-	2630636		2640246-				
(m AGL)		2562235	2630701					2692314	
1.0	NW		11	A1	45	A1	45	A1	45	A1
2.0	NW		12	A2	12	A2	12	A2	12	A2
3.0	NW		13	A3	13	A3	13	A3	13	A3
4.0	NW		14	A4	14	A4	14	A4	14	A4
5.0	NW		15	A5	15	A5	15	A5	15	A5
5.9	NW		16	A6	16	A6	16	A6	16	A6
1.0	SW		18	A7	18	A7	18	A7	18	A7
2.0	SW		19	A8	19	A8	19	A8	19	A8
3.0	SW		20	A9	20	A9	20	A9	20	A9
4.0	SW		21	A10	21	A10	21	A10	20	A10
5.0	SW		22	A11	22	A11	22	A11	22	A11
5.9	SW		23	A12	23	A12	23	A12	23	A12
1.0	NE		24	B1	24	B1	24	B1	24	B1
2.0	NE		25	B2	25	B3	25	B3	25	B3
3.0	NE		26	B3	26	B4	26	B4	26	B4
4.0	NE		28	B4	28	B5	28	B5	28	B5
5.0	NE		29	B5	29	B6	29	B6	29	B6
5.9	NE		30	B6	30	B7	30	B7	30	B7
1.0	SE		31	B7	31	B8	31	B8	31	B8
2.0	SE		33	B8	33	B10	33	B10	33	B10
3.0	SE		34	B10	34	B11	34	B11	34	B11
4.0	SE		41	B11	41	B12	41	B12	41	B12
5.0	SE		42	B12	42	B13	42	B14	42	B13
5.9	SE		43	B13	43	B14	43	B15	43	B14

One UVIC was collocated with a digiPID at the 2-m level of the 32-m tower (TIPS), and another was positioned 1 m behind the center of Conex H4 (WAKE). Both UVICs were mounted at a height of 2 m AGL. The TIPS sonic data are found on channel B15, and the WAKE sonic data are found on channel A13.

C. 3 Quartz Thermometer Temperature Probe Positions and Column Numbers (file folder: FOQT)

Column 1: ground surface
Column 2: 0.01 m AGL
Column 3: 0.05 m AGL
Column 4: 0.10 m AGL
Column 5: 0.25 m AGL
Column 6: 0.50 m AGL
Column 7: 1.00 m AGL

Column 8: 2.00 m AGL

C.4 Actinometer Positions and Column Numbers (file folder: Actinometer)

Column 1: Upward Facing PSP (incoming shortwave radiation)
Column 2: Downward Facing PSP (reflected shortwave radiation)
Column 3: Upward Facing PIR (incoming longwave radiation)
Column 4: Downward Facing PIR (terrestrial radiation)
Columns 5-8 Embedded instrument temperatures, not data channels

C.5 Conex Thermocouple Positions and Column Numbers (file folder: CONEXtemps)

a. Conex G7

Column 1: top face
Column 2: northwest face
Column 3: southeast face
Column 4: northeast face
Column 5: southwest face

b. Conex G6

Column 6: top face
Column 7: northwest face
Column 8: southeast face
Column 9: northeast face
Column 10: southwest face

c. Conex G5

Column 11: top face
Column 12: northwest face
Column 13: southeast face
Column 14: northeast face
Column 15: southwest face

d. Conex G4

Column 16: top face
Column 17: northwest face
Column 18: southeast face
Column 19: northeast face
Column 20: southwest face

C.7 PWIDS Station Data (file folder: MUSTPWIDS)

PWIDS data files (Munn1JJJ.DAT) include a two-character test name (MU for MUST) followed by a two-digit station number, and four digits indicating the year (1) and Julian date (JJJ). The data are divided into 8 space-delimited columns: a single digit station identifier; Julian date; time (MST); tens of seconds; wind speed (m s^{-1}); wind direction (degrees, true); temperature (Celsius); and humidity (percent). The time represents the end period of the 10-sec average.

C.8 SAMS Station Data (file folder: MUSTSAMS)

SAMS data files (Munn1JJJ.TXT) include a two-character test name (MU for MUST), a two-digit station number and four digits indicating the year (1 for 2001) and Julian date (JJJ). The data are space-delimited into fourteen columns, twelve of which contain data: a single digit station identifier; Julian date; time (MST); wind speed in miles per hour; wind direction (degrees True); standard deviation of wind direction; maximum wind speed (miles per hour); pressure (mb); temperature (Celsius); relative humidity (percent); and maximum and minimum 15-min temperatures. The time represents the end period of the 15-min average.

C.9 WDTC Sonic Anemometer Locations, Orientations, and Column Numbers

a. The time in each filename for the WDTC sonics indicates the start time of that file in MDT. Time increments forward 0.1 s for each row of data. The data are presented in terse ASCII format with the following sign convention: (1) flow approaching the front of the sonic array produces a + u; (2) flow approaching the sonic array from the left produces a +v; (3) upward vertical motion produces a +w. All speeds are in m s^{-1}. Cross-axis tilt (t) is positive clockwise (up on left, down on right) and along-axis roll (r) is positive when the front of the array is elevated.

b. Turbulence (Vx) probes. All arrays were mounted at a height of 1.15 m AGL. In filename MMddhhmmssvx.dat,

Columns 1-4 (u,v,w,c): 2.5 m northwest of H6, heading 327°
Columns 5-8 (u,v,w,c): in front of G5, heading 150°,
Columns 9-12 (u,v,w,c): between G6 and H6, heading 061°
Columns 13-16 (u,v,w,c): between G6 and G7, heading 148°

c. North pneumatic mast, Sx probes, heading 242°, filename MMddhhmmssnorth.dat

Columns 1-3 (u,v,c): 4 m AGL
Columns 4-6 (u,v,c): 8 m AGL
Columns 7-9 (u,v,c): 16 m AGL

d. South pneumatic mast, Sx probes, heading 058°, filename MMddhhmmsssouth.dat.

Columns 1-3 (u,v,c): 4 m AGL

Columns 4-6 (u,v,c): 8 m AGL
Columns 7-9 (u,v,c): 16 m AGL

e. 32-m tower, 8-m level, Sx probes, heading 240°, filename MMddhhmmss_8_METER.dat

Columns 1-6 (u,v,w,c,t,r): 8 m AGL

f. 32-m tower, 4-, 16-, 24-, 32-m levels, Sx probes, heading 240°, filename MMddhhmmsstower.dat

Columns 1-4 (u,v,w,c): 4 m AGL
Columns 5-10 (u,v,w,c,t,r): 16 m AGL
Columns 11-16 (u,v,w,c,t,r): 32 m AGL

Note: The 32-m data set began with additional channels for the 24-m sonic (u,v,w,c,t,y), but these data were removed when the instrument failed.

C.10 DSTL Sonic Anemometer Locations and Orientations

The DSTL Gill Windmaster sonics were mounted at 2.4 and 6 m AGL on each of the 6-m towers located in the northwest, southwest, northeast, and southeast quadrants of the MUST array. Damaged transmitters limited the number of available channels. Accordingly, available channels were allocated between sonic positions in three different configurations. Table C-2 shows which sonics were providing data during time periods when each of the configurations was in use. DSTL sonic data are presented in raw unrotated binary (.chX) and ASCII (.asX) files, where X is the telemetry channel number. Data units for u,v,w, and c are cm s^{-1}. The sonic data file name convention is DDhhmmss for day of the month, hour, minutes, and seconds for the beginning of the file. Refer to Beck et al. (2001) for details.

Table C-2. DSTL Sonic Anemometer Locations, Orientations, and Data Channels During MUST.

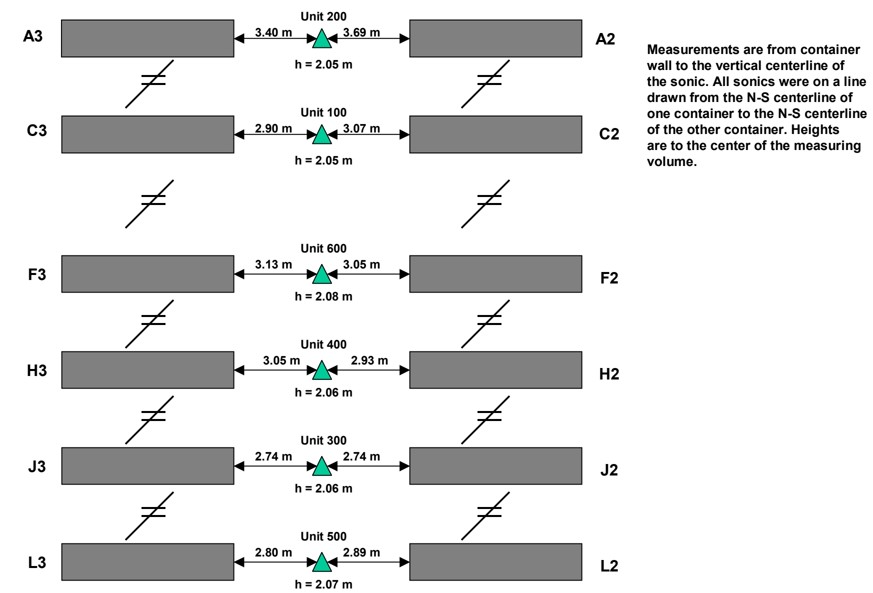
Tower	Height M (AGL)	Azimuth of U Axis[a] (deg)	Data channel – Date (September 2001) 11-14	15-25 (2007 MDT)	25-26 (2026 MDT)
NW	2	178.1	1	1	1
NW	6	177	2	2	--
SW	2	184.7	--	--	2
SW	6	184	4	4	4
NE	2	179.5	--	--	7
NE	6	178	--	3	8
SE	2	186.3	7	7	--
SE	6	185	8	8	--

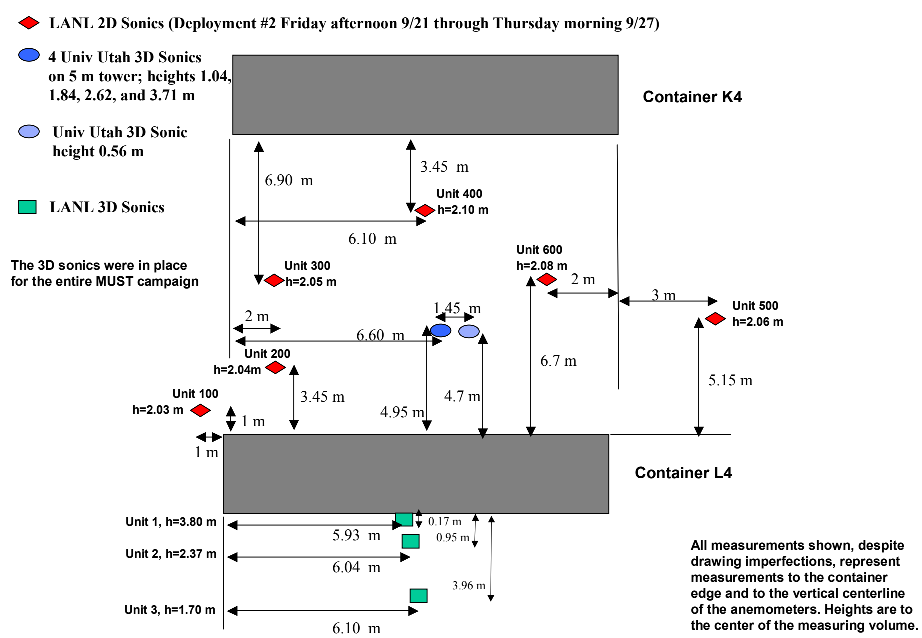
[a]With respect to true north.

C.11 LANL and University of Utah Sonic Anemometer Locations

The LANL 2D sonics were moved from positions shown in Deployment #1 to positions shown in Deployment #2 on 21 September 2001.

LANL 2D Sonic Deployment #1 (Monday afternoon 9/10 through Friday morning 9/21)





C.12 Surface Weather Observations

a. Surface weather observations were taken from the CP during MUST. The observations are contained in a folder labeled MUSTobs on the data CD in a MUSTYJJJobs.txt format. Letter Y is 1 for 2001 and JJJ is the Julian date. Surface observation data were taken from a mobile meteorological station mounted with equipment similar to that used on the PWIDS. The latest 10-s reading is used for the hourly weather observation. Observations are presented in space-delimited column format. From left to right these columns are: temperature (degrees Celsius); relative humidity (%); pressure (mb); density (g m^{-3}); state of ground (0 = dry); cloud cover (tenths); cloud type; cloud base height; visibility (statute miles); present weather in land synoptic code; wind direction (degrees true)/wind speed (ms^{-1}); observer initials, time (UTC).

b. The mobile 2-m meteorological station from which surface weather observation data were taken was located 30 m south of the CP trailer. Ten second-averaged data are presented in files named 2MobsMMDD.txt, where MM is the month (09) and DD is the day of the month. The 10-s readings are presented in space-delimited column format from left to right as follows: date/time; station ID (1025); average wind speed (ms^{-1}); wind direction standard deviation; air temperature (degrees Celsius); instantaneous (1-s) wind speed, wind direction, and temperature; battery voltage; checksum; barometric pressure (mb); relative humidity; checksum.

C.13 Arizona State University Equipment Locations and Data Presented

a. Tethersonde flights were taken from a position approximately 15 m north of the CP trailers. Flight data are contained in folder "Balloon" in the ASU folder on the data CD, which also contains a Must_Readme.txt file that explains the file structure. Data from each flight include: height above mean sea level; pressure (mb); temperature (degrees Celsius); relative humidity (%); wind speed (ms^{-1}); wind direction; potential temperature (degrees Kelvin); virtual potential temperature (degrees Kelvin); and gradient Richardson number. Files are named MMDDHHmm.txt, with 09 for month, DD for the day, HH representing hour in MDT, and mm the minute for the beginning of the flight.

b. ASU fielded two thermistors, one located 3 m AGL at a distance of 0.5 m south of conex L4, and a second thermistor located 0.32 m AGL at a distance of 1.5 m south of conex L4. These data files (u09DDHHmm.dwd), found in the unified folder on the data CD, were taken every 30 s and recorded with respect to MST.

c. One 3-axis ATI sonic anemometer was positioned 32 m south of conex L4 at a height of 1.5 m AGL. Five-minute averaged files named auMMDDHHmm.txt are contained on the data CD, with the hour and minutes (HHmm) at the beginning of the averaging period in MDT. Data presented include 5-min averages of wind speed, wind direction, temperature, velocity components, and derived statistics for friction velocity, heat flux, and Reynolds stress.

APPENDIX D. MUST TEST PARTICIPANTS

D.1 WDTC PARTICIPANTS

Fred Baney (Meteorological Technician)
Roland Barbero (Meteorological Technician)
Christopher Biltoft (Test Director)
Jimmie Calhoun (Meteorological Technician)
George Cochran (Electronics Technician)
William Grayson (Meteorological Technician)
Doug Hawkins (Electrician)
Evans Long (Crane Operator)
David Petrie (Electronics Technician)
Mario Sandoval (Audio-Visual Technician)
Pfred Toensing (Audio-Visual Technician)
Ed Buys (Electronics Technician)

D.2 Defense Threat Reduction Agency/Logicon RDA

Patrick Cavenee (Logicon)
Gary Ganong (Logicon)
Ed Toton (Logicon)
John Pace (DTRA)

D.3 Army Research Laboratory

Sam Chang
Ron Cionco
Giap Huynh
Ramaz Kvavilashv
Young Yee

D.4 Los Alamos National Laboratory

Michael Brown
David DeCroix
Gerald Streit

D.5 Defence Research Establishment Suffield

Geoff Chandler
Peter Kosteniuk
Eugene Yee

D.6 Arizona State University

Marko Princevac (Yugoslavia)
Dragan Zajic (Yugoslavia)

D.7 Defence Science and Technology Laboratory

Nicola Beck
Ian Griffiths
Chris Jones
Doug Strickland

D.8 National Oceanic and Atmospheric Administration

Scott McLaughlin

D.9 University of Utah

Matt Nelson
Eric Pardyjak

APPENDIX E. ABBREVIATIONS

AGL	-	above ground level
ARL	-	Army Research Laboratory
ASU	-	Arizona State University
ATI	-	Applied Technologies, Inc.
CD	-	compact disk
CP	-	command post
DCP	-	data collection platform
digiPID	-	digital photoionization detector
DOE	-	Department of Energy
DPG	-	Dugway Proving Ground
DRES	-	Defence Research Establishment Suffield (Canada)
DSTL	-	Defence Science and Technology Laboratory (UK)
DTRA	-	Defense Threat Reduction Agency
FM-CW	-	Frequency modulated- continuous wave
FOQT	-	Fiberoptic quartz thermometer
IR	-	infrared
IRIG	-	inter-range instrumentation group
ISL	-	inertial sublayer
LANL	-	Los Alamos National Laboratory
MDT	-	Mountain Daylight Time
ML	-	mixed layer
MOS	-	Monin-Obukhov similarity
MSL	-	mean sea level
MST	-	Mountain Standard Time
MUST	-	Mock Urban Setting Test
PBL	-	planetary boundary layer
PC	-	personal computer
PID	-	photoionization detector
PVC	-	polyvinyl chloride
PWIDS	-	portable weather information and display system

RSL	-	roughness sublayer
SAMS	-	surface atmospheric measurement system
UK	-	United Kingdom
UTC	-	Universal Coordinated Time
UVIC	-	ultraviolet ion collector
WDTC	-	West Desert Test Center
WMD	-	weapons of mass destruction

APPENDIX F. DISTRIBUTION LIST

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